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configuring for resilience and sustainability

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Structural Embeddedness and Supply Network Resilience

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Abstract

Manufacturing companies do not exist in isolation. In this paper we contribute to the understanding of supply network disruptions by relating structural complexity to network robustness and resilience. We first simulate a manufacturing network based on the suspension part supply chain of a major European automotive producer. We then subject the network to failures by disrupting production on different firms that are embedded within this network. We find that as embeddedness characteristics of disrupted firms vary, so do the network's ability to withstand disruption and recover. Beyond demonstrating how structural embeddedness effects network resilience, we also illustrate which embeddedness measures matter the most. Our work contributes to our understanding of how topological properties relate to supply network resilience, and thus constitutes an important step towards generating better risk mitigation strategies in supply chains today.

Introduction

Manufacturing and supply chains can fail, and when they do, the implications are often catastrophic. In the aftermath of the March 2011 Japanese earthquake, damage at a few key suppliers in the Tohoku area caused the highly interconnected auto industry to shut down. Not only Japanese producers, but also European and North American manufacturers had to halt production soon after their inventories from Japanese suppliers dried up. This resulted in an estimated loss of one-third of the daily global automotive production, translating into 5 million vehicles worldwide, out of the 72 million planned for 2011. Shortly after, Honda UK had to halve its production, and Toyota UK announced plans to cut back on shifts. Goldman Sachs estimated that the shutdowns cost automakers $200 million a day (Kurtenbach 2011).

Complex interdependencies that cause this domino effect are a matter of significant concern for many industries, but their dynamics and potential impact are currently unpredictable (Linton and Choi 2011). Interdependent manufacturing networks emerge as companies procure parts from one another, and invest in each other. Such local interactions result in a macro system of interdependencies, but individual companies have no visibility over this extended network and how it impacts them (Choi et al 2001). This lack of knowledge resulted in the long-standing assumption that the emergent structure is linear, and chain-like (Fig. 1 a). Virtually all analytical and simulation models that investigate the effect of interdependencies are built on such assumptions (New 2004). However, these linear systems do not represent reality, because the boundaries of manufacturing are now large-scale and global, as management methods such as just-in-time and sophisticated ICT tools resulted in increased efficiency and mass outsourcing, creating a complex structure with loops, hubs, and various patterns that create consistent systemic effects (Fig. 1 b). As the first empirical study of its kind, we recently discovered that there is a 23% chance that global automotive suppliers do not only supply to top tier clients, but also to one another, significantly impacting a variety of system wide and local properties such as robustness and resilience (Brintrup et al 2011). Heterogeneous structures means that firms are embedded in the network differently, hence their levels of network dependence varies and so do the network's dependence on them. Yet there is paucity of research that studies the relationship between embeddedness and system resilience, which form the topic of our investigation in this paper.

In what follows, we briefly examine related literature (Section 2), present how network structural embeddedness can be measured in a supply network context (Section 3), present details of our methodological approach (Section 4), before summarising and discussing the results of our analysis (Sections 5 and 6).

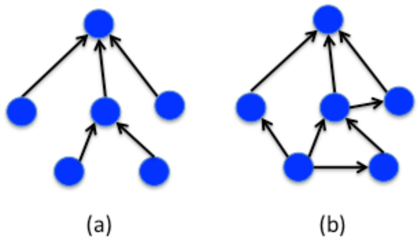

Figure 1. (a) A linear supply chain (b) a complex supply chain with lateral connections

Brief overview of literature

The issue of resilience and risk management within supply networks has become a significant research topic in recent years – stimulated not least by catastrophic events such as the March 2011 Japanese earthquake, and the Thailand floods in July 2011.

While some research reviews the practical strategies adopted by individual firms (Brindley 2004; Craighead et al 2007; Zsidisin and Ritchie 2008; Christopher et al 2011), other researchers developed analytical and simulation based models to examine risk exposure (for example, Tomlin 2006; Chaturvedi and Martínez-de-Albéniz 2011). However, most of this work focuses on dyadic relationships between suppliers and clients.

Many researchers have stressed the importance of considering supply chain ideas from a network perspective (for example, Easton and Axelsonn 1992; De Toni and Nassimbeni 1995; Olsen and Ellram 1997; Lazzarini et al 2001; Lamming 2000; Harland et al 2004). However, progress has been constrained by a lack of analytical tools to describe and interpret network structures. The last decade has seen the emergence of a toolbox of techniques under network science for understanding the characteristics of complex networks (Watts 2003; Newman 2010). Network scientists stressed the importance of structure in system robustness and resilience (Barabasi and Albert 2000). While Choi et al (2001, 2002, 2009) and Borgatti and Li (2009) have pioneered the application of these ideas to supply networks, this new analysis perspective is still in its infancy.

We find three related empirical studies on supply networks, comprising Choi et al (2001)'s efforts to map part of the Honda, Acura, Daimler Chrysler, which consisted of 70 members; Lomi and Pattison (2006)'s analysis of 106 automotive firms in southern Italy; and Keqiang et al (2008)'s examination of the Guangzhou automotive industry, consisting of 84 firms. However, despite these efforts, the relationship between robustness and resilience, and network structure remained unexplored in the context of supply networks.

The primary contribution of this paper is to relate the notion of structure in supply chains and to supply chain robustness and resilience. We will do so by generating an empirically based model of an automotive suspension material flow network and measure the structural embeddedness patterns of firms in this network. Following this, we simulate disruptions on the network by systematically halting production on each firm, and observing the relationship between the impact on system output and structural embeddedness.

Measuring network structural embeddedness

The supply network under investigation here consists of an inherent material flow logic carried out by multiple actors along various pathways, with the goal of producing a final consumer-facing product at the focal firm. Hence, a firm does not only depend on its immediate suppliers, but indirectly, to the suppliers of its suppliers, all the way to the bottom of the chain. If a supplier's supplier fails or underperforms, subsequent firms might be impacted, even if they do not depend on that supplier, because the effort devoted to remedy the failure will render it likely that focus is shifted from operations on which other clients are dependent. Similarly, an underperforming client may mean that not only the supplier is impacted, but also the suppliers' relations suffer from resulting operational dependencies. Such chains of dependency imply that the decision that every individual firm takes on the number of relationships it sustains might indirectly impact firms in its extended network.

Quantifying the extent of dependencies in a network is nontrivial. Four metrics emerge from literature: *degree centrality, closeness centrality, betweenness centrality*, and *product market share centrality*.

The degree-centrality C_D of the node i in a non-directional network is defined as:

$$C_D(i) = \sum_j x_{ij} = \sum_j x_{ji}$$

where x_{ij} is the binary variable equal to 1 if there is a link between n_i and n_j and equal to 0 otherwise. Bringing the network view to the operational context of a supply chain, Kim and Choi (2011) differentiate between supplier and client links, noting that the direct number of supplier links a firm has (*in-degree centrality*) is relational to the firm's operational load, making them instrumental in carrying out the architectural or technical changes in products that flow across. On the other hand, the number of direct clients (*out-degree centrality*) is related to the firm's load in demand integration and resource allocation. The operational load and demand integration perspective put forward by Kim and Choi (2011) brings on the need to develop an understanding of directionality when considering positioning in the supply network. Therefore the centrality measure is modified as:

$$C_{D,out}(i) = \sum_j x_{ij}, \qquad C_{D,in}(i) = \sum_j x_{ji}$$

where x_{ij} is equal to 1 if there is an outgoing link between n_i and n_j and equal to 0 otherwise; and x_{ji} is equal to 1 if there is an incoming link from n_j to n_i and equal to 0 otherwise .

Closeness centrality measures how close a node is to all the other nodes in the network beyond the ones to which it is directly connected. The metric is frequently used in identifying which node can reach to others faster and consequently relates to a node's power and influence in the network (Freeman 1979). Kim and Choi (2011) illustrate that this metric would capture a supply firm's autonomy as the closer the firm is to other firms, the more information will be visible to it, which should translate into operational benefits. In the context of operational dependencies, closeness of a node to others can be used to capture the speed with which a firm is impacted from the inadequacies of its supplying firms, and disseminates it. This is because firms that are close to every other firm in the network are more likely to be among the first impacted by the performance of other firms and also more likely to impact others.

$$C_{C,out}(i) = \sum_j \frac{1}{d_{ij}}, \qquad C_{C,in}(i) = \sum_j \frac{1}{d_{ji}}$$

where $C_{C,out}$ refers to out-closeness centrality and $C_{C,in}$ to in-closeness centrality. The closeness-centrality C_C of node i is defined as the sum of the reciprocal distances to $\left(\frac{1}{d_{ij}}\right)$ or from $\left(\frac{1}{d_{ji}}\right)$ all the other nodes, considering the shortest paths.

Betweenness centrality in the study of networks examines the number of times a node sits on the shortest paths that link any two nodes on the network. Kim and Choi (2011) note this metric's relevance to supply chains as: "*Firms with high betweenness act as a hub or pivot that transmits materials along the supply chains, and betweenness centrality relates to the extent to which a firm potentially affects the downstream firms' daily operations (e.g., lead time) and eventually the performance (e.g., final product quality) of the whole network.*" The betweenness centrality C_B of node i is:

$$C_B(i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$$

where g_{jk} is the total number of shortest paths linking the two nodes j and k, and $g_{jk}(i)$ is the number of those shortest paths that contain i.

When it comes to investigating robustness, supply networks should not only be examined by their abstract structure but also by the distribution of production on their structure (Brintrup et al 2011), who defined a "*Product market share" M* as:

$$M(i) = \frac{1}{M_{\max}} \left[\sum_{p}^{P_i} \left(\frac{1}{d_p} \right)^{\alpha} \right]^{\frac{1}{\alpha}}, 0 \le M(i) \le 1$$

where P_i is the total number of product categories offered by supplier *i,* d_p is the number of instances product p is supplied in the network, M_{max} is the maximum product market share found in the network, multiplied to normalize the measure, and α is a constant. To illustrate the meaning of the measure, consider the case of a firm making a single unique product. If the firm that produces a unique product in the network is disrupted, it is very likely that the entire supply chain will be disrupted. In this case, the sum in the brackets would equal 1, which is maximal. In general, both the production of more products and the rarity of each product contribute to increasing *M(i)*. Parameter α allows us to control how we weigh these two factors against each other. When α is 1, the number of products a firm has and the rarity of them carry equal importance, and as α becomes larger the firms offering unique products will dominate this measure. After experimentation with a range of values, we decided to take a value of 2 for α as this value is conservative enough to take both variables into account, without the rarity of product offering dominating the analysis or eliminating the importance of firms producing multiple products.

Given the several relevant measures that can characterize how a supplier is embedded in the network, experimentation with structures that present a variability of these measures could indicate their significance in the context of resilience. Next we present the empirical context in which we examine the relationship between the above measures and resilience.

Research Methodology

Data

Our empirical context is the production of suspension parts in the automotive industry because this choice allows us to use primary network data from a single database managed by an independent agency, making data collection convenient and the dataset comprehensive (Marklines Automotive Information Platform[1]). We searched for supply base of an OEM in this database, and also worked with the OEM, who cross-validated our network map to be representative of how it procures suspension parts. Our construction includes the OEM's three main suspension assemblers, and their secondary and tertiary suppliers along with product categories offered by each firm.

It should be noted that the firms within the dataset define themselves as automotive manufacturers. While their clients might or might not be members of the automotive industry, the data is primarily automotive focused, and therefore does not include raw materials supply. Furthermore, product categories are generic categories drawn by the datasource, rather than focussed on specific models. As such, the analysis should be taken as suggestive rather than definitive, as we essentially consider the production capabilities of two firms the same if they declare that they produce the same type of product.

Figure 2 shows the overall network structure. Firms are represented by nodes and supply relationships among firms are represented by directional links. The network consists of 83 suppliers, 18 suspension components, and 148 relationships. Three main suspension assemblers are illustrated at the centre. These act as hubs that procure suspension components. Observation of the degree distribution shows that the network topology is non random but hub-based, in that most nodes have a small number of connections, and a small number of nodes connect to a large number of other nodes. This is important, as the resulting embeddedness measures are non-uniform across the network, making the analysis more insightful.

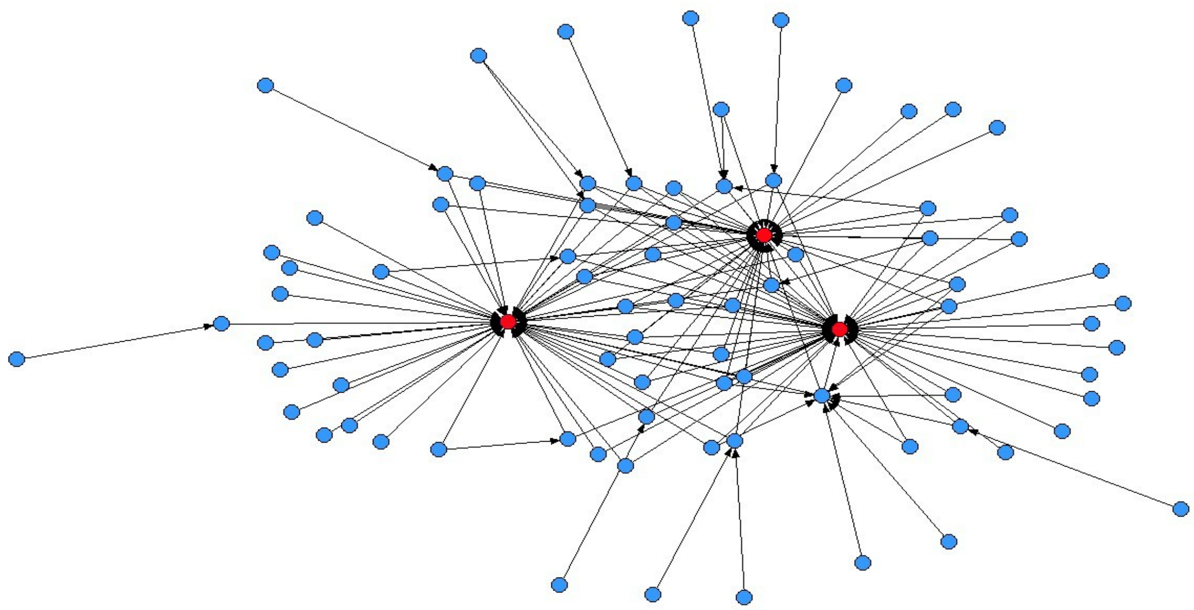

Figure 2. Network map: Three assemblers are depicted in the centre of the network in red colour.

Modelling and Analysis

In the literature, the terms resilience and robustness are not used consistently. Here, we adopt a distinction, which defines *robustness* as a system's ability to withstand a one-off shock, and *resilience* to refer to a system's ability to adapt and recover from a problem. A further measure of resilience could include examining system stability after recovery is attempted. In this paper we

[1] www.marklines.com

examine the relationship between a firm's structural embeddedness and that firm's contribution to system robustness and resilience. Hence structure is kept constant, while the network is disrupted by failing individual firms for a given time period.

In order to do so, Discrete Event Simulation is used. An empirically based model is created where each firm supplies a given component or set of components to its clients, and assemblers create the suspension assembly. Production variables are uniform throughput the network: the amount produced per component and the time it takes to produce each component are the same, and delivery time is instantaneous. This is unrealistic, however at the same time necessary to easily isolate the effects of topology on output variables. The production model is pull-based, in which the focal assemblers generate periodic, constant numbers of orders and trigger the flow of materials. The model is allowed to run for a set number of iterations for warm up in a time period t_1, which allows us to observe undisrupted mean throughput (μ_{t_1}). We then select and disrupt a firm for a given period of time t_2, during which the firm does not produce the set of products it normally supplies. At time period t_2 the firm resumes production. During each run of the experiment only one firm is disrupted and time intervals are the same for each run. Batch orders and bills of materials are not considered for ease of experimentation, and it is assumed that at least one instance of each products category should exist to produce the assembly. We examine robustness by observing the difference between mean system throughput between t_1 and t_2, i.e. μ_{t_2}. The production is then left to run for a period of time t_3, which is equivalent to the initial warm up period. This allows us to observe variance in mean throughput after recovery as a proxy to resilience (Var_{t_3}). All time periods are decided after experimentation with the model and differences in output variables between separate experimental runs under the same conditions are observed to be negligible.

Following experimentation with each firm's failure, we carry out statistical analysis to identify those firm embeddedness characteristics that cause most disruption to the network and those that cause the most volatility.

Results

Table 1. Pearson correlation between network variables

	$C_{D,out}$	$C_{D,in}$	$C_{C,out}$	$C_{C,in}$	C_B	M
$C_{D,out}$	1					
$C_{D,in}$	0.27	1				
$C_{C,out}$	0.83	0.19	1			
$C_{C,in}$	0.26	0.99	0.18	1		
C_B	0.29	0.98	0.21	0.98	1	
M	0.30	0.41	0.26	0.41	0.36	1

Table 1 shows the Pearson correlation between network variables. It appears that many variables are highly correlated. C_B is correlated with $C_{D,in}$ and $C_{C,in}$, which themselves are correlated, whereas $C_{C,out}$ is correlated with $C_{D,out}$. This is expected because the more number of connections a node has, the closer it will be to every other node in the network by definition. Similarly, the more connections a node has, the more of an intermediary role that node will have, as it essentially acts as a bridge connecting material flow. The issue with high correlation is that in our subsequent regression analysis, including highly correlated variables in the same model would give rise to multi-collinearity, making the significance of individual variables uninterpretable. After creating a base model in which all embeddedness measures are examined (Base Model in Table 2), we refrain from using correlated variables in subsequent models. Variable inflation factors (VIF) have been calculated to examine multi-collinearity in each model, where a value over 10 is considered to be multi-collinear according to Cohen et al (2003).

Table 2 shows results. In both base models for μ_{t_2} and Var_{t_3} the VIF is high. After experimenting with combinations of all embeddedness measures, two measures were observed to affect both robustness and resilience significantly, without being correlated to one another. These are $C_{C,out}$ and M (see Model 1.2). As these values increase the mean system throughput decreases, and variance in throughput after recovery increases. Firms that have high out-closeness centrality are those that are pivotal in distributing incoming material to all other nodes in the direction of outgoing flow. This means that system robustness and resilience are strongly linked to the vulnerability of firms that are most close to clients in the network. It also highlights that it is not only the number of clients a firm has that matters, but also "total closeness", which includes the number of clients of a firm's clients, and their clients, all the way to the focal firm. In addition to this structural ingredient, the distribution of production over the network matters. Firms that produce rare products and have a large number of products in their portfolio are the ones that disrupt the network most. Interestingly M and Centrality measures are not highly correlated in our data in this case. We experimented with a further model (see Model 1.3) to study the effect of both properties taken together and included an interaction term ($C_{C,out} * M$). It appears that when both values increase, the output starts to decrease significantly, due to the combination effect. The model can be interpreted as the following: throughput starts to decrease if M increases only if $C_{C,out}$ is greater than 38.48/104.49=0.37. Similarly, throughput decreases when $C_{C,out}$ increases only if M is greater than 25.35/104.5=0.25. A similar effect takes place in the case of Var_{t_3}. This is interesting because it is shown that the combination effect is more than the effect of individual variables. Note that the VIF of models that include the combination effect are slightly higher than the limit of 10, but this is expected and does not make the model uninterpretable in combination based models (Cohen et al 2003).

Table 2. GLS Regression results

	μ_{t_2}			Var_{t_3}		
	Base Model	Model 1.2	Model 1.3	Base Model	Model 2.2	Model 2.3
$C_{D,out}$	4.35			-0.5		
$C_{D,in}$	83.52			-30.77		
$C_{C,out}$	-5.65**	-8.62**	25.35***	0.28	-0.08	-2.60***
$C_{C,in}$	-78.43			31.17		
C_B	-1.83			1.46		
M	-68.17***	-47.08***	38.48***	3.04***	3.34***	-3.02***
$C_{C,out} * M$			-104.49***			7.77***
Maximum VIF	2628.01	10.07	11.07	2782.29	8.01	11.00
F-statistic	3.52E-11	2.41E-12	4.56E-20	8.53E-11	21.07E-12	4.66E-13
Number of observations	80					
$p < 0.10$; * $p< 0.05$; ** $p < 0.01$;*** $p < 0.001$						

Discussion and conclusions

While there have been many studies on resilience and robustness in supply chains, there is a paucity of research concerning these properties from a structural perspective. Those few which do exist raise the question of complex network effects, namely it appears that many types of lateral dependencies may exist in a supply chain, but their extent and impact is unknown. Empirical studies to address these questions have been largely absent from literature. To address these issues we explored the phenomenon of structural robustness and resilience in supply chains using a model based on data from a major automotive producer and examined how the embeddedness patterns of various firms in this network can be related to the amount of disruption they can cause if they fail. After reviewing literature from network science and supply networks, a number of measures were extracted, and a production model was created to simulate failures of firms. A regression analysis was then carried out to relate embeddedness measures to robustness and resilience, proxied by mean difference in throughput after disruption and variance after recovery.

The first lesson from this work is that structure matters when it comes to system resilience. Latest research points us in the same direction, urging supply chain researchers to investigate lateral relations in supply networks (Choi and Wu 2009, Borgatti and Li 2009). Of course this does not mean models of flow, risk and uncertainty relating to simple hierarchical structures are redundant, but it means that they need to be extended to consider multiplicative and cascading effects resulting from embodiment in a complex network.

The second lesson is that embeddedness measures need some thought before translation in a supply network context. Some measures might be more important than others, and new measures may need to be developed to capture additional properties. For instance this paper showed that firms that are closer to others in the direction of outgoing flow disrupt the network most, which is not surprising when put in the context of material flow. In addition, the rarity and size of production portfolios are important. Of course, context would also be important to characterize other types of supply networks where links represent contractual relationships rather than material flow presented in this paper. In addition, the detailing of these models need to be carefully considered - detailed production data might make risk analysis more accurate but, also more challenging. For instance product volume and production and delivery scheduling could be variables that can significantly enhance or cripple resilience, however the inherent heterogeneity of such variables will necessitate a leap in complexity modeling.

Establishing a complex network view on supply chains is challenging as this type of analysis often needs large-scale data, which can be hard to collect due to confidentiality reasons and lack of traceability. However this analysis shows that visibility can be important and effort needs to be devoted in understanding the governing patterns in the system (Choi et al 2001).

We see two main avenues for further research. The first is a need to gain a deeper understanding of the relationship between system resilience and network structure. Additional disruption scenarios such as geographical disruptions and logistic issues could further our understanding. Comparative studies between different industries would be valuable to examine the generalizability of findings. Secondly, dynamic changes in the network such as alternative sourcing could be considered. Longitudinal observation of empirical networks help us understand patterns of recovery, and observe how supply networks behave when subjected to different types of disruptions.

References:

1. Borgatti S. and Li, X. (2009). On social network analysis in a supply chain context. Journal of Supply Chain Management, 1/1: 7-22.
2. Brindley, C. (ed.) (2004). Supply Chain Risk. Farnham: Ashgate.
3. Brintrup A., Kito T., New S., Reed-Tsochas F. (2011) Mapping out the Toyota supply Network: The emergence of resilience, Working Paper 11-05-012, University of Oxford (available from www.cabdyn.ox.ac.uk).
4. Chaturvedi, A. and Martínez-de-Albéniz, V. (2011). Optimal procurement design in the presence of supply risk. Manufacturing and Service Operations Management, 13/2: 227-243.
5. Choi T. Y., Dooley K. J., Rungtusanatham M. (2001), Supply networks and complex adaptive systems: control versus emergence, Journal of Operations Management 19: 351–366
6. Choi T. Y.; Kim Y. (2008), Structural embeddedness and supplier management: a network perspective, Journal of Supply Chain Management; 44(4): 5-13.

7. Choi, T.Y. and Wu Z. (2009), Taking the leap from dyads to triads: Buyer-supplier relationships in supply networks, Journal of Purchasing and Supply Management, 15:263-266.
8. Christopher, M., Mena, C., Khan, O. and Yurt, O. (2011). Approaches to managing global sourcing risk. Supply Chain Management: An International Journal, 16/2: 67-81.
9. Cohen P, Cohen J, West SG, Aiken LS. 2003. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences (3rd edn). Erlbaum: Hillsdale,NJ.
10. Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J. and Handfield, R.B. (2007) The severity of supply chain disruptions: design characteristics and mitigation capabilities. Decision Sciences, 38/1: 131-156.
11. De Toni, A.F. and Nassimbeni, G. (1995). Supply networks: genesis, stability and logistics implications, a comparative analysis of two districts. Omega - The international Journal of Management Science, 23/4:403-18.
12. Easton, G. and Axelsson B. (1992). Industrial Networks: A New View of Reality. Routledge, New York.
13. Freeman, L.C., 1979. Centrality in networks: I. Conceptual clarification. Social Networks 1, 215–239.
14. Harland, C. Zheng, J., Johnsen, T. and Lamming, R. (2004). A conceptual model for researching the creation and operation of supply networks. British Journal of Management, 15 /1:1–21.
15. Keqiang W., Zhaofeng Z., and Dongchuan S. (2008). Structure analysis of supply chain networks based on complex network theory. In: Proceedings of the Fourth International Conference on Semantics, Knowledge and Grid. Washington, DC, USA: IEEE Computer Society. 493-494.
16. Kim Y., Choi T.Y., Yan T., Dooley K. (2011) Structural investigation of supply networks: A social network analysis approach, Journal of Operations Management 29:194-211.
17. Kurtenbach E. (2011), As Japan shutdowns drag on, auto crisis worsens, Associated Press, 28 March
18. Lamming R.C. (2000). Japanese supply chain relationships in recession, Long Range Planning, 33/6:757-778.
19. Lazzarini S.G., Chaddad F.R., Cook M.L. (2001), Integrating Supply Chain and Network Analyses: The Study of Netchains, Journal of Chain and Network Science, 1(1):7-22
20. Linton T., Choi T. Y. (2012) HBR Blog Network, Yes, You Can Predict Supply-Chain Disasters
21. Lomi A., Pattison P. (2006), Manufacturing relations: an empirical study of the organization of production across multiple networks, Organization Science, 17(3): 313-332
22. New, S. (2004) Supply Chains: Construction and Legitimation. In: Understanding Supply Chains: Concepts, Critiques, and Futures. Oxford University Press, Oxford. ISBN 0199259321
23. Newman, M.E.J. (2010). Networks: An Introduction. Oxford: Oxford University Press.
24. Olsen, R.F., Ellram, L.M. (1997), Buyer–supplier relationships: alternate research approaches. European Journal of Purchasing and Supply Management 3:221–231.
25. Tomlin B. T. (2006), On the value of mitigation and contingency strategies for managing supplychain disruption risks. Management Science 52(5):639–657.
26. Watts, D. 2003. Six Degrees: The New Science of Networks: The Science of a Connected Age. New York, Heinemann.
27. Zsidisin G. A. and Ritchie, B. (eds.) (2008). Supply Chain Risk: A Handbook of Assessment, Management and Performance. New York: Springer.

Assessing Resilience in Agriculture: Case Study at G's Growers

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ABSTRACT

Resilience is a key requirement for a modern agricultural organisation. Climatic variation can both severely influence the growing cycle for different products and can also affect retailer order volumes as consumers vary their buying habits significantly in the face of unseasonal temperatures. For the grower, who can often plant crops up to 6-9 months in advance, this can place extreme pressures on the supply chain, requiring him to accelerate/decelerate crop development or source crops from alternative sources. This paper focuses on the assessment of resilience capabilities of ~~a~~ an agricultural organisation focusing on one product. A prototype tool for assessing the operational resilience of an industrial organisation developed at Cambridge is adapted for this purpose. Potential disruptions to steady operations are analysed and the ability of the organisation to manage in the face of these disruptions is assessed.

1. Introduction

A recurring theme in the manufacturing industry over the past two decades has been resilience. The Oxford English Dictionary defines resilience as 'the capacity to recover quickly from disruptions'. This report considers resilience not only as the capacity to recover, but also the ability to continue to achieve operational goals in the presence of disruptions. Research has been conducted into assessing the responsiveness of manufacturing operations ~~1~~, which has been gradually developed into a framework which can be used to audit a manufacturing process, providing an overview of the disruptions it faces, the impacts these cause and the capabilities the business has to respond. This framework has been applied to a number of manufacturing and service operations (e.g. See Matson and McFarlane, 2001, Thorne, 2010). However it has not been applied in agriculture nor in fact in any instances where the operations are so widely distributed and tightly dependent on environmental conditions.

Resilience is key requirement for a modern agricultural organisation. Climatic variation can both severely influence the growing cycle for different products and can also affect retailer order volumes as consumers vary their buying habits significantly in the face of unseasonal temperatures. For the grower, who can often plant crops up to 6-9 months in advance, this can place extreme pressures on the supply chain, requiring him to accelerate/decelerate crop development or source crops from alternative sources.

This paper focuses on the assessment of resilience capabilities of an agricultural organisation, G's Growers, based in Cambridgeshire in the UK. Potential disruptions to steady operations are analysed and the ability of the organisation to manage in the face of these disruptions is assessed. The specific aims of the paper [and the work reported] have been:

1. To propose a framework for auditing the resilience of agricultural processes, by adapting an existing framework for assessing manufacturing disruption management capabilities; and
2. To implement this framework in case study focusing on the iceberg lettuce supply chain at G's Growers.

2. Approach To Assessing Resilience Via Disruption Analysis

2.1 Overview

The approach taken to developing an agricultural resilience audit has been to adapt an existing approach developed over 10 years for assessing response capabilities of manufacturing production operations (Matson and McFarlane, 1999). Each step of the existing tool was reviewed with key differences between manufacturing and agricultural operations in mind and a revised audit then formed the basis for the case study reported in this paper.

2.2 The Cambridge Disruption Management Assessment Framework

The existing framework for auditing operational resilience was developed more than ten years ago at the Institute for Manufacturing at the University of Cambridge (Matson & McFarlane, 2001). The framework comprises a series of analysis tools applied in sequence to a specific manufacturing operation that examine the goals, disruptions and responses to disruptions that most affect it. An outline of the framework is given in Figure 1.

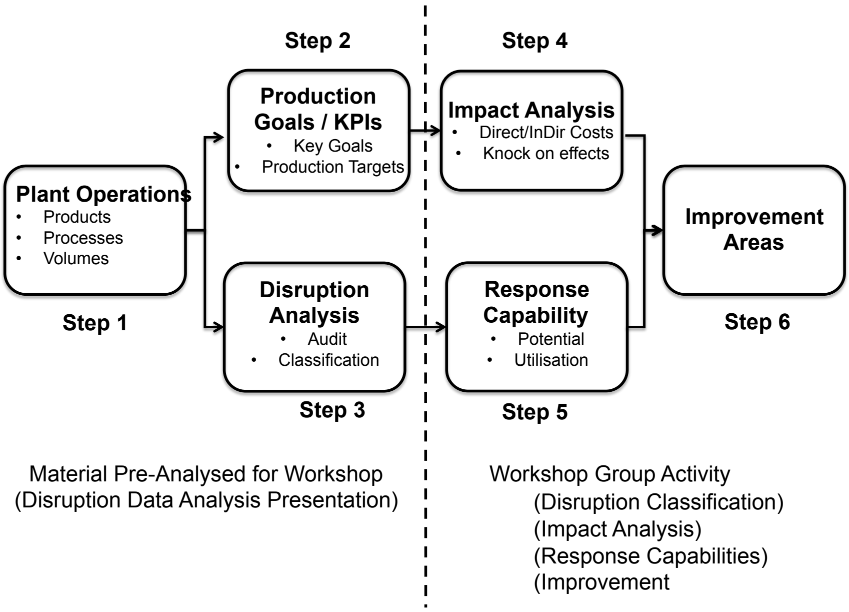

Figure 1 Operational Resilience Audit

The six steps of the resilience audit are as follows:

1. Operations: This is the initial step in the auditing process. This requires the auditor(s) to become familiar with the operations of the company and process that is being assessed. Along with products and processes, information systems, buffers and decision processes should be investigated.

2. Operational Goals: In order to audit the process and analyse impacts of disruptions, it is key to establish the operational goals of the business. This will have an impact on how the severity of disruptions is analysed.

3. Disruption/Scenario Analysis: Firstly a set of disruptions must be identified, along with their effects on the key KPIs of the business (linked to operational goals). After this, future scenarios can be considered: impacts that employees consider a threat on the horizon.

4. Impact Analysis: This information is collected using a qualitative approach which considers the effect of disruptions on delivery, cost and quality of a product. Disruptions should be analysed in terms of the level of disruption they cause, along with their frequency and duration. This information is collected through the use of workshops.

5. Response Capability: The ability to respond should be considered as a sum of the abilities to:

- Recognise and communicate the issue;
- Make a decision effectively;
- Provide buffer capabilities or absorption mechanism and
- Adapt production/operate in an altered state.
-

6. Improvement Areas: Through consideration of both the impact analysis and the resilience capability work, areas can be identified as recommendations for improvement for the audited process/ operation.

Through this chain of tools a picture can be developed of the key disruptions that affect an operation and the capabilities that are in place to deal with them. The process leads to a prioritised improvement plan – essentially a structured approach to improving resilience.

2.3 Adaptations To The Audit For Agriculture Study

In the preliminary meetings at G's Growers as well as throughout the case study it became apparent that there were some issues of difference between the G's Growers operations and typical production operations audited in the past:

- Variable External Environment: weather directly affects production operations and customer order volumes.
- Non Steady State Operations: Significant variations between all products over time and space.
- Dispersed operations: The operations occur over several counties so there is little overall visibility on a daily basis.

- Strategic and tactical disruption issues: Long term issues such as land availability affect operations as much as short term issues.
- Limited opportunities to adjust processes: Once commenced the planting process can only be influenced in a minor way by external control.
- Cycle time >>> Order lead time: Orders arrive on a daily basis while the planting lead time is 4-9 months depending on the season.

The effect of these factors on the nature of disruption management and hence the way the audit might need to be executed is:
- Disruptions and the prevention of their impact is a daily challenge for an agricultural company.
- Many potential disruptions are averted before their impact is felt
- There are some potential disruptions which occur very infrequently but if they occur they can be disastrous.
- Some disruptions are relevant to cycle time while others relevant to order lead time.

Some of these factors needed to be simply taken into account within the existing framework – for example dealing with *potential* disruptions alongside a*ctual* disruptions. Others required some adaption to the framework itself – e.g. the consideration of both tactical / operational and strategic disruptions and assessing the corresponding capabilities for dealing with them

Figure 2 Audit Adapted for Assessing Agricultural Resilience

The next section details the G's Growers case study using this adapted audit.

3. Agricultural Resilience Case Study

3.1 Introduction To Iceberg Lettuce Supply Chain

Through its marketing agent, G's Fresh, G's Growers is responsible for the growth and selling of 104 different products, supplied to major grocery retailers, wholesale distributors (e.g. markets) and food processors. The company is set up using a co-operative business model, with a core number of growers based in the Fens, along with other growing members in other parts of the UK and Spain. Through the application of such a business model, the farmers are able to take advantage of economies of scale through the pooling of resources and also the combination of central administrative functions. G's is the largest UK salad vegetable supplier, and aims for year round supply. In order to do this, members of the co-operative in Spain grow iceberg and other crops during the winter, ensuring supply when the climate in the UK is not suitable for growing such crops. Other co-operative members based in the UK are responsible for summer supply to UK customers from May-October.

The process for growing lettuce can be split into three broad categories: Harvesting & Packing→ 1. Pre-field: processes which take place before the crop is in the ground (in greenhouses) 2. In-field: processes that occur in the field in which the crop is being grown 3. Post-harvest: processes that occur once the mature crop has been harvested in field. The three phases and the steps within each are illustrated in the different shadings in Figure 3.

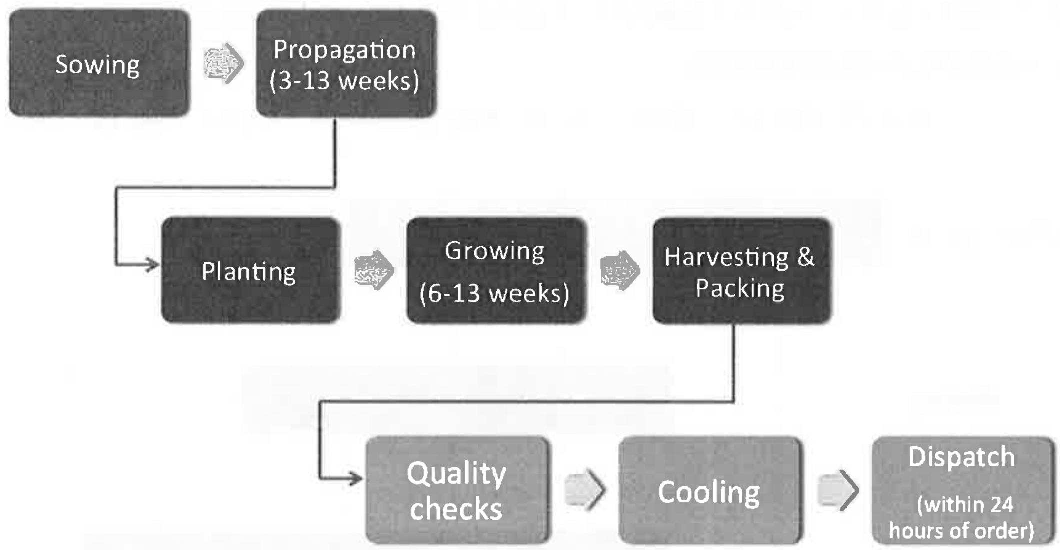

Figure 3 Iceberg Lettuce Production Process

3.2 Conducting The Resilience Audit on the Iceberg Lettuce Operations

The audit of the iceberg lettuce production process was carried following the process outlined in Figure 2. Because of the very tight time scales allocated to the case study and very limited availability of key personnel for workshops the study was compressed somewhat and where possible the input of a few key experts was used to prepare workshop material so that each activity could be completed in 2-3 hours.

In the following sections some of key outputs are given along with comments on how the analysis took place. (It is intended that the study be written up more fully in a future paper.)

3.3 Disruption Analysis and Classification

Disruptions were initially captured through interviews with staff. Disruptions were captured at different points of the process chain and were then classified by the nature of the disturbance. Three categories were initially used:

1. Variation - disturbances to do with variations in product quality, processes etc.

2. Interruptions - disturbance that causes a temporary shortage in supply.
3. Disasters - disturbance that fundamentally threatens the process' ability to function.
However, the classification system of the disruptions was changed during the process. This was with a view to the response capability work: it appeared to be more logical to classify the disruptions by the area of the operation they effected. The areas of the operation were split into the following categories:

1. Supply (of materials/processes to G's Growers)
2. Processes - Further split into 2.1 pre-field, 2.2 in-field and 2.3 post harvest
3. Demand (from customers)

This revised classification was adopted for two main reasons. Firstly, it was felt that there would be the possibility that response capability approaches, which would be discussed later on in the process, would be easily transferable within these three groups. Secondly, the stakeholders for each of these groups were distinct from one another and often located in separate geographical locations. Figure 4 outlines the main disruptions identified in each of these areas.

1 Supply	2.1 Pre-field	2.2 In-field	2.3 Post Harvest	3 Demand
Chemical legislation	Machine issues	Unseasonably cold weather	Queues for cooling	Short term order variation
Land availability	Germination Variation	Freak weather	Specification risk	Micro Contamination in industry
Peat availability and quality		Variation in yield	Haulage delays	Immediate order variation
Labour availability		Peat block variation	Packaging outside specification	
Seed availability		Mildew	Microbiological Contamination	
		Pest infestation		
		Machine issues		
		Long warm periods		

Figure 4 Key Sources of Disruption (and Resilience Challenges)

3.4 Disruption Impact Analysis

The impact on the business of each of the disruptions identified in Figure 4 was simply addressed by combining a severity assessment with a frequency estimate.

In order to assess the severity of the disruptions, a list of effects was drawn up. Each effect was then scored with a severity relative to the other effects. This was carried out on a scale of 1-5, with 5 being the most severe. During the workshop, employees would be asked to determine which effects were relevant to which disruptions, and this would then be recorded. However, it became clear that there was some double scoring due to the list of effects. Certain effects were intrinsically linked to each other, and hence appeared in tandem. This was rectified through consultation with the employees at G's.

In order to assess frequency of disruption, a scale of 1-5 was developed. This was scored using the following categories tailored to the case study:

1. Occurs less than once per season
2. Occurs once per season
3. Occurs two to three times per season
4. Occurs once a month
5. Occurs every one or two weeks

The information for each of the disruptions was then captured and analysed. The effects of each of the disruptions could be grouped into three categories: 1. Delivery 2. Cost 3. Quality The severity of the disruption on each of these dimensions of impact was the combination of all of the effects in that dimension. Additionally disruptions were split at this point into operational/tactical or strategic disruptions as discussed earlier. The details of the impact analysis are withheld here but those disruptions identified as most critical as a result of the analysis are given in Figure 5.

.Operational Disruptions	Strategic Disruptions
Immediate order variation	Irrigation restrictions
Short term order variation	Labour availability
Mildew	Chemical legislation
Pest infestation	Land availability and quality
Specification risk	
Peat availability and quality	
Peat block variation	

Figure 5 Critical Disruptions for Iceberg Lettuce Operations

3.5 Resilience Capabilities

The approach for assessing the resilience capabilities was based on the existing framework with the information being collected through the use of an interactive workshop. The existing framework suggests that resilience capability depends on four abilities within an organisation: recognition, decision-making, absorption/buffering, and adaptability. Recognition refers to the ability to quickly identify an issue and to make this information available. Decision-making is the ability to quickly determine the most effective resilience to minimise the disruption. Absorption or buffering ability is the capacity to mitigate the impact of the disruption through the use of buffers or other absorption mechanisms. Finally, the adaptability is the capability to alter the state of the operation to a different mode, thereby reducing the impact of the disruption. The final two dimensions of resilience capability were deemed quite technical and whilst typical of the language found in a factory, are not standard concepts in agriculture. To simplify, they were combined into the term 'Action'. This would be used to capture the mechanism(s) that the company used to deal with disruption.

Figure 6 illustrates the capability analysis results for the operational disruptions.

Operational Disruption	**Recognition**	**Decision**	**Action**	**Average**
Immediate order variation	1	3	3	2.3
Short term order variation	3	3	2.5	2.8
Mildew	2	2	2	2
Pest infestation	3	2	2.5	2.5
Specification risk	1	2	1.5	1.5
Peat availability and quality	2	1	1	1.3
Peat block variation	1	1	2	1.3

Figure 6 Relative Resilience Capabilities

3.6 Prioritising Resilience Improvements

The final step of the resilience analysis involved the combination of the impact and resilience capabilities. A generic form of the resulting chart is given in Figure 7. Clearly those issues of most interest are those in the top left corner of the chart.

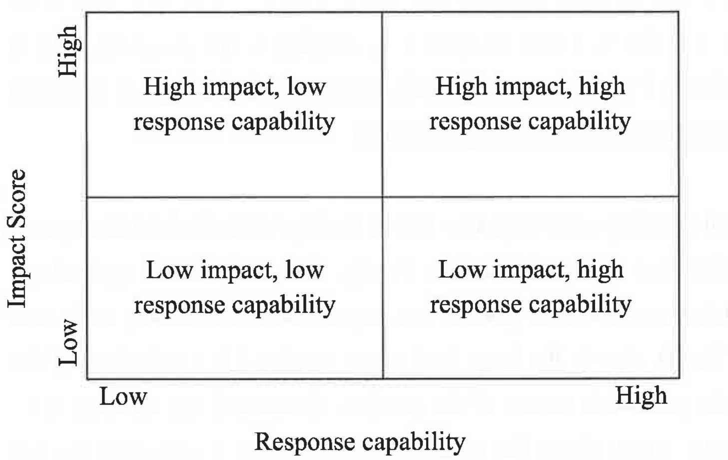

Figure 7 Impact v Capability Chart.

The chart resulting from the analysis of the Strategic disruptions is given in Figure 8 where the issue of land availability is indicated as being a key issue and is in fact well known to G's Growers as an ongoing challenge.

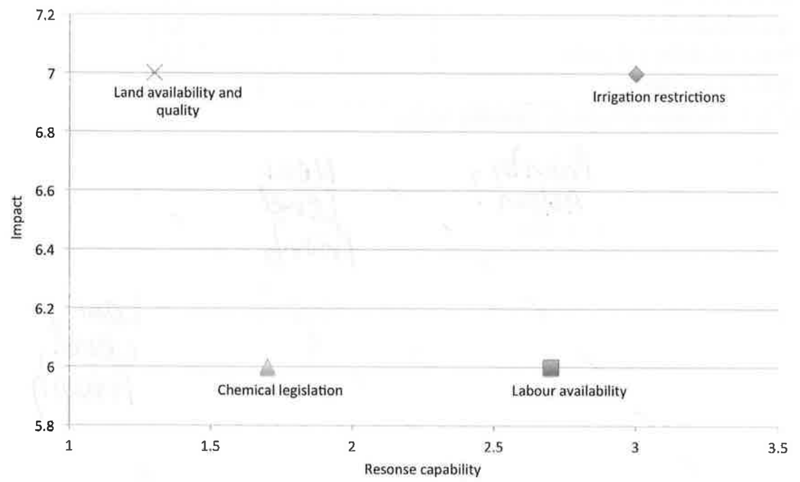

Figure 8 Impact v Capability Chart for Strategic Disruptions

4 Conclusions and Future Work

4.1 Conclusions

- *Applicability of Operational Resilience Audit to Agricultural Operations:* The existing framework worked relatively well, with only a few changes required to the overall structure. The main changes related to how each stage of the process should be carried out in an agricultural business. The overall structure has been changed to reflect the need for agricultural businesses to take a long-term view of disruptions, as well as a short-term operational view. This is due to the inherent inability to affect the productive base of the organisation, which is intrinsically linked to the availability and quality of land and irrigation systems.
- *Resilience Of G's Growers Iceberg Lettuce Operations:* The study showed that because of the nature of their operation – one of continual threat of disruption - G's Growers demonstrated a remarkably high level of resilience in the face of many tactical challenges. At a strategic level – on a year by year basis there are issues that could be addressed in greater detail such as land availability.
- *Differences Between Manufacturing and Agricultural Resilience Challenges:* the specific differences in the case of the particular study were highlighted in Section 2. In general the very high level of disruptions from the external environment, the lack of visibility due to dispersement of operations and the significant mismatch between cycle time and order lead time are quite fundamental issues which might be expected to apply quite generally.

4.2 Future Work

This paper reports on a single agricultural case study of an adapted audit and as such any conlusions drawn must be qualified. Further testing and some streamlining of the auditing process needs to be carried out before the process can be deemed to be a reliable approach to assessing agricultural resilience.

5. Reference

Matson, J, McFarlane, D, (1999) Assessing the Responsiveness of Existing Production Operations, in International Journal of Operations and Production Management, v19, n8, pp765-784.

Resilience – capabilities and future directions in global supply networks

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Abstract

Volatile and unpredictable market conditions bear considerable supply chain (SC) risks, such as excess cost or lost sales due to e.g., customer delivery problems or quality impairments. Accordingly, under such conditions, resilience – i.e., a firm's capability to adequately handle unforeseen disturbances and still retain or recapture a competitive state of business – is an important source of business success. This paper aims to identify individual and organizational capabilities in global supply networks that may typically influence a company's resilience. As resilience is a rather new concept, several fragmented research traces will be inspected in order to develop a substantial conceptualization of supply chain resilience and to systematize links to neighboring fields like risk management or SC-agility.

Keywords risk management, supply chain network, resilience, resilient capabilities.

1. Introduction

Over the past ten decades, for most companies the economic conditions have changed immensely for most companies: stable patterns have turned into volatile and unpredictable demands. Often, supply chain operations are distributed over huge geographical distances and involve heterogeneous SC-partners. Hence, a company's processes such as labor and human knowledge, material supply, technical equipment and financial resources are also exposed to considerable uncertainties and risks. Interdependencies between companies have grown together remarkably through supply network density density, product and service variety, and operational complexity.

With growing volatility and uncertainty, the ability to act in a flexible manner and manage risks has gained more importance. Research fields like risk management (Manuele 2005; Blackhurst et al. 2008) has gained importance among researchers and practitioners. In most cases the explicit or implicit objective was to "mitigate" occurring risks (Kunreuther 2006; Kaplan and Mikes 2012) in order to return to the previous and (again) stable operating status. Triggered through growing risks and increased amounts of supply chain disruptions, these developments were further extended towards questions like robustness and resilience: being able to act in a flexible way and to adapt to changes could either mean to return to a previous and stable equilibrium state after being affected by supply chain disturbances or attain a new equilibrium point that might require changed capabilities compared to the previous operating state. For example resilience has been defined (Fiksel 2003) as the ability to survive, adapt and grow in the face of turbulent change. Here, concepts like efficiency, flexibility and adaptability are explicitly assumed to belong to a complex bundle of capabilities that constitute resilience. Multiple examples (Hofmann 2006) have shown the immense potential impact of small disruptions (financial risks, company risks) as well as severe natural disasters on companies and even whole supply chain sectors. Hence, the need for resilience is non-controversial (Pettit 2008). However, many questions are still left open, as resilience is a rather new topic especially in a SCM-context. This paper aims to identify individual and organizational capabilities in supply chains based on existing literature that may typically influence a company's resilience and help or hinder companies in returning to a previous stable (and economically successful) equilibrium state or to attain a new equilibrium point. The identified capabilities function as comparison basis for finding an interview series that is currently being executed based on Grounded Theory Methodology (Manuj and Pohlen 2012). Finally, based on the result of the structured literature review being the content of this paper and the findings within the interviews the authors are confident to identify a set of individual and organizational capabilities that enable or hinder companies to become resilient.

The structure of the paper is as follows: initially a structured literature review (Denyer and Tranfield 2003) was conducted regarding resilience and related issues. Subsequently, the findings are (were?) contrasted to previous findings to identify individual and organizational capabilities in supply chains influencing a company's resilience. The final conclusion compiles questions with particular relevance for further research related to SC-resilience.

2. Research Methodology

For the systematic identification of literature the authors followed the guideline provided by Tranfield (2003) to give an overview of the definition of "risk" and "resilience" since 1960 and potential individual and organizational capabilities in the field of supply chain.

The review consists of 5 stages:
Stage 1 - "planning of the review"
Stage 2 - "conducting the review"
Stage 3 - "quality assessment"
Stage 4 - "data extraction and monitoring"
Stage 5 - "data synthesis"

Stage 1 - Planning the review

The first step was to verify the need for systematic research to identify individual and organizational capabilities to make organizations more resilient. This includes the scoping of the literature in the field of "risk capabilities" and "resilient capabilities" for supply chains. Risk management is well defined and used as a common tool with a high impact on resources in a company's business (Manuj und Mentzer 2008; Kaplan und Mikes 2012; Hertz und Thomas 1983; Eccles et al. 2001) Furthermore it takes into account that risk management shows limitations as *"Risk management is non-intuitive; it runs counter to many individual and organizational biases. Rules and compliance can mitigate some critical risks but not all of them. Further we tend to be overconfident about the accuracy of our forecasts and risk assessments and far too narrow-minded in our assessment of the range of outcomes that may occur"* (Kaplan und Mikes 2012), managing those unforeseen disruptions is complex.

Similarities and differences between the constructs "supply chain risk" and "supply chain resilience" have been analyzed and beyond that individual and organizational capabilities identified (being the basis for further in-depth research) which companies may need to face challenges in business nowadays. However risk management lacks in its ability to assess the complexities of supply chains, evaluate the "*intricate interdependencies of threats and prepare a firm for the unknowns of the future*" (Hertz and Thomas 1983). It further shows "*disadvantages concerning costs and capacities, and needs systematic strategies so that a company that wants to use the technique defines its relevance exactly*" (Carter 1972). Knowing the fact that risk management is a complex method for a company's daily business, requiring high capacity and management effort, resilience has become more and more important for company managers. Therefore we took into account that risk management is part (a management tool) of resilience and focus on resilience capabilities in our further research work.

Stage 2 – Conducting the review

In stage 2 research board members were defined. The board members were three professors from two faculties (one in Austria and one in the US), senior researchers and doctoral students who were already working in the field of flexibility and resilience. Those experts were supported by practitioners that deal with "Risk management" and "Resilient ideas/startups". Furthermore several keywords such as "risk", "resil", "capabilities", and "supply" were defined for the literature review. The search in the Ebsco database was conducted by using the keyword "resilience". In the Science Direct database, the search was done in the "expert search" option using "risk" AND "resil" AND "capabilities", with no diversification in title or abstract. The complete search was conducted in all the databases: "Emerald", "Ebsco" and "Science direct". The literature review showed (see Table 1) that there are many implications from other research fields on resilience (e.g., public fields, community resilience, psychology or nature catastrophes (Stewart et al. 2009), but less in the field of supply chain resilience capabilities with EBSCO and Science Direct being the preferred sources to identify literature based on resilience.

Keywords	searched with:	Database		
		EBSCO	Emerald	Science Direct
Risk & Resilience & Supply	1 *risk*+*resil*+*supply*	92*	2	24'
	2 *risk*+*resil*+*supply* in Abstract	42*	0	24'
	3 *risk*+*resil*+*supply* in Title	2*	0	24'
Risk & Resilience & Capabilities	1 *risk*+*resil*+ *capabilities*	34*	0	19'
	2 *risk*+*resil*+ *capabilities* in Abstract	23*	0	19'
	3 *risk*+*resil*+ *capabilities* in Title	0	0	19'

Table 1: Extraction of literature research

The publications identified based on this search methodology functioned as the basis for the following quality assessment attempting to identify those papers which meet all criteria.

Stage 3 Quality Assessment

For this research, the table (based on Brown, 2007) below was used to preselect the potential literature in this research. Only "*studies that meet all the inclusion criteria*" (Tranfield, 2003) are included in the review process mentioned in the reference section.

Elements	Level			
	0 - Not applicable	1 - Low	2 - Medium	3 - High
Literature Review	this study does not meet research criteria	literature review is inadequate, no meeting criteria	basics included, issues of the topic discussed	deep and borad knowlede of relevant literature
Theoretical clarity	this study does not meet research criteria	different theories; basic concepts not clear	author explains others, but no significant theoretical growth	clear defined theory
Theoretical robustness	this study does not meet research criteria	no underlying theory; generalizations not usefull for further study	author links on others, new concepts still not significant	knowlede about theory, creates new theories
Contribution	this study does not meet research criteria	no important contribution, no advantage shown	builds upon other theories	the author makes new contributions to existing knowlede, fills gap
Strength of the paper	this study does not meet research criteria	many generalizations, no advantage shown, no theoretical backround	the author mentions others, does not contribute new concepts	the author presents a good picture of the theory, shows limitations and comes up with new theoretical input

Table 2: Quality assessment table adapted from Brown, 2007

Stage 4 Data extraction and monitoring

The monitoring and extraction of relevant data was done in an excel worksheet to collect the definitions and capabilities of resilience and to have the possibility to easily restructure and update the table when new findings (e.g. new capabilities) in added papers were identified. In this stage further literature that was identified when examining the selected papers in-depth was added.

By taking a look at the publishing timeline of resilience related topics, it can be shown that the field of "resilience in supply chains" is quite new (see Table 3).

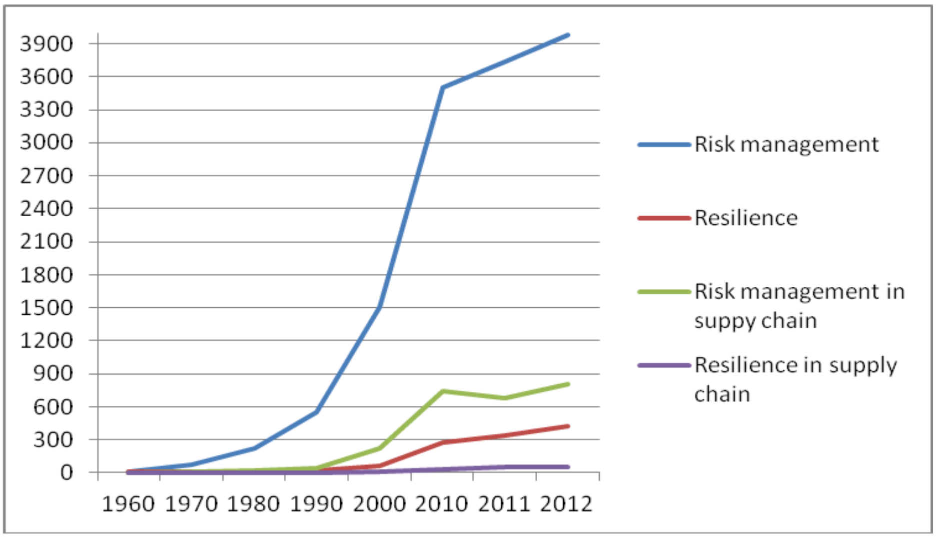

Table 3: Publications since 1960

The research of (Pettit et al. 2010) contributed to defined capabilities of resilience in a company (defined in a case study research) and how to measure the “zone of balanced resilience” (Pettit et al. 2010).

Furthermore (Sheffi 2007) describes how companies act and design strategies and processes for resiliency:

“*Resilient companies communicate obsessively, keeping all managers aware of strategic goals, tactical factors, and the day-by-day, even minute-by-minute, pulse of the business*.”

Up to this point, resilience has been well structured from a demand perspective as seen in a framework of (Pettit 2008). However, there is limited research concerning capabilities needed to further understand resilience in practice as well as possible different types of resiliency capabilities depending on different types of industries or different strategic alignments.

The growing complexity of supply chains and the issue for managers which “*struggle to find appropriate ways to tackle supply chain risk management*” (Peck 2005) in an arguable manner is growing. “*Long term dedication”* and a *“continual process*” (Manuj and Mentzer 2008) have been two major descriptions in literature to face and manage risks nowadays. However, addressing risks is still one of the major problems for companies not knowing what will happen in the future. *“Risks are all those things that keep you away from the perfect path and perfect outcomes and (you) have to be able to translate (risks) into dollars somehow”* (Manuj and Mentzer 2008). Therefore supply chain resilience came up a as “*proactive method that can complement and enhance traditional risk management and business continuity planning”* (Pettit 2008) for companies facing risk and disruptions. Supply chain resilience deals with multiple types of risks at multiple stages of the risk management process. To support management strategies and save costs for further detailed analysis, resilience has become one of the major topics to help practitioners making decisions in the face of adversity (Stewart et al. 2009). Resilience helps to operationalize disaster management plans and/or business continuity and to take action within a given context (Stewart et al. 2009). Environmental catastrophes such as storms or water flooded areas require a proactive decrease a proactive decrease in disaster planning and management to secure survival. Discussions of the challenges and complexities of disaster management frequently allude to community resilience as an important ingredient (Norris et al. 2007).

“Resilience determines the ability of systems to absorb changes, and stability is the capacity of systems to return to an equilibrium state after a temporary disturbance” (Ponomarov and Holcomb 2009). Furthermore, Sheffi (2007) defined resilience as the “*ability of a material to return to its former shape after a deformation*” and resilient organizations are able to *“bounce back” to its pre-disruption level of manufacturing, providing service for customers, or any other relevant performance metric.* The literature was summarized to identify details of the required capabilities for a company’s resiliency.

The literature review indicates that resilience is no replacement for risk management, which is still used as the traditional tool in a company’s daily business. Furthermore resilience is more a proactive method which needs individual capabilities to develop and adjust for company use.

For the further understanding of resilience in supply chains, the author came up with the following definition:

"Resilience is a concept which helps companies to proactively absorb changes and withstand disruptions by using traditional tools while developing their individual and organizational capabilities to survive and grow in volatile markets"

Stage 5 Data synthesis

There are many different resilience capabilities mentioned in literature, but those capabilities lack in consistent glossary and scope. Due to this, it is not possible to simply list them to give practical advice and further case study use. As defined by (Blackhurst et al. 2011), there are "enhancers" and "reducers" for resilience in the supply chain, which affects resources or "flow units" in the company process. However, due to individual company requirements and the defined environment, capabilities may have different characteristics (e.g. the automotive industry requires a lot of flexibility, whereas the steel industry focuses on changing commodity markets). According to these requirements, companies need to define their required capabilities and adjust the maximum possible grade. Company strategies are the "ground floor" for decisions and goals, the directory to develop individual and organizational resilience capabilities.

Therefore the authors clustered and structured capabilities extracted from theoretical and empirical sources, into:

- Enabler of resilience, which determines the adjustment of capabilities and the maximum possible degree of resiliency.
- Strategy of resilience, which builds the "ground floor" for company goals and capability decision making.
- Target of resilience, to survive and become robust and sustainable.
- Capability of resilience that has to be adjusted to reach the goal under a given enabler and strategy.

Enabler of resilience

The aim of the research was not to identify the enabler of resilience, but during the data synthesis the authors defined certain capabilities mentioned in literature as enablers due to their characteristics. In the following, three enablers have been identified which strongly influence the resiliency of a company:

- Organization
- Financial strength
- Complexity

The *organization* belongs to one of the major influences and is a formable enabler for growth in resilience. There are, on the one hand, *"organizational learning processes to evaluate the lessons from incidents and recommend corrective actions"* (Stewart et al. 2009) but also required **"***human resource structures, policies, skills, and culture"* (Pettit et al. 2010) for companies to develop. However, not only the processes, learning enablers and structures play a major role for resilient skills, there is an approach for resiliency which "*can be understood as differentiable from, but complementary to, risk analysis, with important implications for the adaptive management of complex, coupled engineering systems"* (Park and Seager 2013).

This implies that strategies and management procedures in organizational structure need to manage complex environments and adapt to changes when challenges occur. Pettit (2008) underlines this in his dissertation work by saying that *"managing supply chain resilience is a proactive method that can complement and enhance traditional risk management and business continuity planning"*. The organizational structure also appears in managing community disasters where "d*iscussions of the challenges and complexities of disaster management frequently allude to community resilience as an important ingredient"* (Norris et al. 2007). To gain an enhanced resilient supply chain and indeed make it possible, companies need to create a *"risk management culture in the organization"* (Christopher and Peck 2004). Finally ending up with all useful capabilities for a resilient organization, it "*is not only "hardened" to withstand disruptions of all kinds, but is also more competitive on a day-to-day basis. Furthermore, resilient enterprises can consider disruptions to be opportunities rather than problems"* (Sheffi 2007).

Financial strength is mentioned by (Pettit et al. 2010) saying that it is the "c*apacity to absorb fluctuations in cash flow"*. Pettit implies that companies need to have, for example, insurance as well as financial reserves and liquidity for resilient capability needs.

Complexity is described within the company network as "*development and understanding of the intricate systems in which they participate"* (Fiksel 2003). Furthermore, complexity is mentioned in process level and lean management methods by "s*treamlining the flow of supply, and eliminating less profitable product and portfolio complexity"* (Hofman and Aronow 2012) for more resilient processes.

Strategy of resilience

As mentioned above, the data synthesis findings not only came up with capabilities for a company's resilience, but also two strategies of resilience were identified due to their characteristics

- Market position
- Security

The *market position* is defined as the "status of a company or its products in specific markets" (Pettit et al. 2010). The authors mention product differentiation, customer loyalty and brand equity as some of the major resilience influences.

Security has become more important since the world trade center attack, as well as the internet/ cyber security observations (in press since 2013). (Pettit et al. 2010) mention security as the *"Defense against deliberate intrusion or attack"*.

Targets of resilience

In the following three targets of resilience were identified, which describe the outcome of a company gaining resilient skills due to their characteristics:

- Robustness
- Sustainability
- Survivability

O'Rourke (2007) defines *robustness* as *"the inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality*." However, Fiksel (2003) states that *"robustness will be achieved through resilience rather than resistance which"* leads to the conclusion that resilience is rather a function to gain robust skills and strength in a system, but not withstand any external demand. (Azevedo et al.2012) also mentions that *"strategies used to achieve a robust SC also contributes to resilience"*. Aven (2011) underlined this with the statement that *"Resilience is related to the concept of robustness"*. For the function of robustness, the authors often relate to community resilience whereas, for example, virus attacks are one of the major issues (Aven 2011)
Sustainability is mentioned by Fiksel, (2003) stating that a *"resilience perspective has important implications for companies that wish to become more sustainable"*. In further research (company case study's) we would like to gain more information about the function of sustainability.
Survivability is the heart for companies to withstand disruptions nowadays. Pettit et al. (2010) mention that the *"concept of supply chain resilience can fill these gaps and supplement existing risk management programs, thus enabling a supply chain to survive unforeseen disruptions and create competitive advantage*" However, to achieve the function of survival the "*early detection of a disruption"* (Sheffi 2007) is one of the major elements.

Capabilities of resilience

Some of the analyzed publications are based on empirical findings (e.g. Pettit et al. 2013; O'Rourke 2007; Sheffi 2007; Sheffi et al. 2005,) but most are based on theoretical findings (Aven 2011, Azevedo et al 2012, Carvallo and Azevedo 2012, Christopher and Peck 2004, Fiksel 2003, Gilbert 2012; Hofman and Aronow 2012, Norris et al. 2007, Park and Seager 2013, Pettit 2008, Pettit et al. 2010, Pickett 2006, Ponomarov and Holcomb 2009, Stewart et al. 2009;). The following table 2 gives an overview of the identified main sections:

- Enabler of resilience
- Strategy of resilience
- Target of resilience
- Capability of resilience

Each stated main section includes different perspectives and descriptions of authors which have been allocated and clustered. In the following paragraphs the capabilities are identified and clustered into 6 main capabilities for resiliency:

- Changeability
- Innovativeness
- Flexibility
- Efficient collaboration
- Visibility
- Sensing

	Year	2011	2012	2012	2004	2003	2012	2012	2007	2007	2013	2008	2010	2006	2009	2007	2005	2009
Capabilities of resilience	Author	Aven	Azevedo	Carvalho et.al.	Christopher ; Peck	Fiksel	Gilbert	Hofmann	Norris et. al.	O'Rourke	Park;Seager	Pettit	Pettit	Picket	Ponomarov ;Holocomb	Sheffi	Sheffi; Rice	Stewart et. al.
Changeability					x		x	x			x	x			x			
Innovativeness				x		x	x			x						x	x	
Flexibility				x	x			x		x			x		x	x	x	x
Efficient collaboration													x					
Visibility											x		x					
Sensing											x							

	Year	2011	2012	2012	2004	2003	2012	2012	2007	2007	2013	2008	2010	2006	2009	2007	2005	2009
	Author	Aven	Azevedo	Carvalho et.al.	Christopher ; Peck	Fiksel	Gilbert	Hofmann	Norris et. al.	O'Rourke	Park;Seager	Pettit	Pettit	Picket	Ponomarov ;Holocomb	Sheffi	Sheffi; Rice	Stewart et. al.
Target of resilience																		
Robustness		x	x			x				x								x
Sustainability						x												
Survivability													x			x		
Enabler of resilience																		
Organization					x				x		x	x	x	x		x		x
Financial strength													x					
Complexity						x		x										
Strategy of resilience																		
Market position													x			x		
Security													x					

Table 2: Overview of defined major sections of resilience

Changeability

Changeability in the context of this paper is the ability to quickly align processes (on an individual and organizational level) in the direction of an expected outcome. This subsumes that there are several levels within a company which have to be analyzed.

Given this definition, capabilities mentioned in the literature such as:

- Agility
- Changeability
- Adaptability
- Innovativeness (short term)
- Responsiveness

are briefly described in the following and subsumed into the capability of "changeability" for further research.

Agility	*Agility* is defined by Christopher and Peck (2004) as "*being able to react quickly to unpredictable events and is clearly a distinct advantage in an uncertain environment*". Ponomarov and Holcomb (2009) state that "*resilient processes are flexible and agile and are able to change quickly*". O'Rourke (2007) specifies it as "*Rapidity: the speed with which disruption can be overcome and safety, services, and financial stability restored*" and leads to practical input for company conversion.
Changeability	*Changeability* has been identified in different statements and at different company levels. Gilbert (2010) mentioned that there are: "*Two routes to resilience:* Furthermore Ponomarov and Holcomb (2009) mention the process view for resilience and stated that: "*resilient processes are flexible and agile and are able to change quickly*. Pettit (2008) points out the importance of the capability of changeability in a way that, as he states, "*a resilient supply chain has the capacity to overcome disruptions and continually transform itself to meet the changing needs and expectations of its customers, shareholders and other stakeholders*".
Adaptability	*Adaptability* should be a very important capability for the success of a company. Hofman and Aronow (2012) stated that "*companies that move fastest into global markets with innovative products - coupled with supply chains that are customer-driven, adaptable to change and resilient to disruption - will be the winners.*" To adapt to changes and develop innovative products Gilbert (2010) calls it *"transformation A", companies should reposition the core business, adapting its current business model to the altered marketplace"* for more resilient strategies. Ponomarov and Holcomb (2009) state that *„a resilient supply chain must be adaptable, as the desired state in many cases is different from the original one" (there was an extra space here)* and imply the courage to change the way of doing daily business and logistics.
Innovativeness	*Innovativeness* is stated in two different ways: • long term understanding for continuous processes. (= due to the definition of a single resiliency capability) • short term application to bounce back into a steady process level. (= given the definition of changeability, subsumed under this capability)

	In the short term application companies not only need to have continuous innovation and renewal they also need to have "*the ability to recover from the disturbance*" (Carvalho et al. 2012) for resiliency.
Responsiveness	*Responsiveness* is the "*ability to recover from the disturbance and is related to the development of responsiveness capabilities*" (Carvalho et al. 2012). However, (Stewart et al. 2009) further mention "*responsive infrastructures that facilitate efficiency in recovery*" implementing resilient structures.

Innovativeness (long term)
Innovativeness in this context describes the long term strategy of the company to develop, for example, new processes and products to survive continuously in volatile markets. Based on this definition the capabilities of:

- Innovativeness
- Redundancy

are described in the following and subsumed into the capability of "Innovativeness" for further research.
Innovativeness related to resilience is stated as *"companies that wish to ensure their long-term resilience must reach beyond their own boundaries and develop an understanding of the intricate systems in which they participate, and strive for continuous innovation and renewal"* (Fiksel 2003) and is an important capability for companies to ensure resiliency.
Redundancy allows the company to think of "*alternate options, choices, and substitutions under stress*" (O'Rourke 2007). The option to recover from disturbances "*is related to the development of responsiveness capabilities through redundancy and flexibility*" (Carvalho et al. 2012). In 2005 Sheffi and Rice pointed out the achievement of resilience in companies by either "*creating redundancy or increasing flexibility*" (Sheffi et al. 2005). Sheffi (2007) confirms that there are two ways to build resiliency "*through redundancy and through flexibility*".

Flexibility
Flexibility in this context points out that processes need to be able to change quickly. Furthermore, it takes into account that if disruptions occur, companies need to react and change strategies and processes, as necessary for the situation, to satisfy customer needs.
Based on this definition, the capabilities of:

- Flexibility
- Capacity
- Resourcefulness

are described in the following and subsumed into the capability of "flexibility" for further research.
Flexibility seems to be an important capability stated by many authors. Ponomarov and Holcomb (2009) talk about resilient processes in a way that they *" are flexible and agile and are able to change quickly"* whereas Pettit et al. (2013) specifies "*Flexibility in Sourcing*" as the "a*bility to quickly change inputs or the mode of receiving inputs*" as well as the "*supplier*

contract flexibility" as the capability to use *"multiple sources' flexibility in order fulfillment"* or the *"ability to quickly change outputs or the mode of delivering outputs"*. Hofman and Aronow (2012) also relate flexibility on the supplier side and speak about "*increasing long-term alternative sources of raw materials and logistics capabilities"*. However, they further mention that the capability of "*designing products that allow more flexibility in supply and manufacturing"* is also one of the required resilience capabilities for company success. Being successful underlines that companies need to have the "*ability to recover from the disturbance"* (Carvalho et al. 2012) but this *"is related to the development of responsive capabilities through redundancy and flexibility"* (Carvalho 2012). Sheffi (2007) stated that "*Enterprises can build resiliency in two ways— through redundancy and through flexibility"*. This implies the importance of flexibility required for a company's development of resilient strategies.

Capacity is defined by Pettit et al. (2010) as the *"availability of assets to enable sustained production levels"* The level of production is again mentioned by Hofman and Aronow (2012) defining that the *"expanding outsourced manufacturing capacity"* is one of the capabilities needed to gain resiliency.

Resourcefulness is mainly described in the field of incoming materials as "*increasing long-term alternative sources of raw materials"* (Hofman and Aronow 2012) and very precisely hints at "*not advocating a return to the days of buffering every stage in the supply chain with safety stock or excess capacity. We do suggest that the strategic and selective use of 'slack' may be fundamental to supply chain resilience"* (Christopher and Peck 2004) as well as dealing well with" *logistics capabilities, and expanding outsourced manufacturing capacity* (Hofman and Aronow 2012). It further leads to the "*capacity to mobilize needed resources and services in emergencies"* (O'Rourke 2007) and the capability to "*manage the complexity of anticipated incidents"* (Stewart et al. 2009).

Efficient collaboration

Efficient collaboration in this context describes the importance of communication within a company and externally for fast operating systems and processes.

Based on this definition, the capabilities of:

- Efficiency
- Collaboration

are described in the following and subsumed into the capability of "efficient collaboration" for further research.

Efficiency is defined by Pettit et al. (2010) as the "c*apability to produce outputs with minimum resource requirements"*, but is not further used by any other relevant paper review.

Collaboration within a company or between companies might be necessary to share risks and to be able to forecast in a proper manner. Pettit et al. (2010) calls it the"*Ability to work effectively with other entities for mutual benefit"*.

Visibility

Visibility in this context describes the necessity of transparent structures and processes to identify needs and disruptions quick and implement changes in a possible manner. *Visibility* as defined by Pettit et al. (2010), is described as the "*knowledge of the status of operating assets and the environment*", but is not mentioned by any other author in the extracted literature. Sheffi (2007) further mentions that *"Resilient companies communicate obsessively, keeping all managers aware of strategic goals, tactical factors, and the day-by-day, even minute-by-minute, pulse of the business. Dell employees, for example, have continuous access to product manufacturing and shipment information, as well as to the company's overall status."*

Sensing

Sensing in this context is described as the skill of being delicate in managing good forecasts and realizing processes.

Based on this definition, the capabilities of:

- Sensing
- Anticipation

are described in the following and subsumed into the capability of "sensing" for further research.

Sensing has been mentioned by Park and Seager (2013) as an outcome of a process: "*Instead, resilience is better understood as the outcome of a recursive process that includes: sensing, anticipation, learning, and adaptation. In this approach, resilience analysis can be understood as differentiable from, but complementary to, risk analysis, with important implications for the adaptive management of complex, coupled engineering systems."*

Anticipation is defined as the "a*bility to discern potential future events or situations*" (Pettit et al. 2010) whereas Park and Seager (2013) mention a combination of capabilities being responsible for resiliency in companies:"

The data synthesis identified useful capabilities for further research (Grounded Theory and Case Research) and beyond that the authors noticed that there are basically four groups (listed below) used to understand resiliency:

Enabler of resilience	• adjustment of capabilities and the maximum possible degree of resiliency.
Strategy of resilience	• build the "ground floor" for company goals and capability of decision making.
Target of resilience	• survive to become robust and sustainable.
Capability of resilience	• has to be adjusted to reach the goal under a given enabler and strategy.
Changeability	• ability to react quickly to unpredictable events. • *the speed with which disruption can be overcome and safety, services, and financial stability restored* • adapt to changes and develop innovative products.
Innovativeness	• be able to bounce back into a steady organization and process. • *develop and understand the intricate systems in which they participate, and strive for continuous innovation and renewal*

Flexibility	• be able to react to changes quickly, change structures and processes in case an event occurs • *ability to quickly change inputs or the mode of receiving inputs*
Efficient collaboration	• be able to communicate internally and externally for fast operation. • *capability to produce outputs with minimum resource requirements* • *ability to work effectively with other entities for mutual benefit*
Visibility	• the necessity of transparent structures • *knowledge of the status of operating assets and the environment*
Sensing	• the skill of being very delicate with forecasts and changings • a*bility to discern potential future events or situations*

Conclusion

The contribution of this research was to select quality literature to give an overview of all individual and organisational capabilities influencing a company’s supply chain resilience. During this research it was possible to understand the concept of supply chain resilience and gain a framework for further practical application. Besides resilience capabilities, it seems to be important to understand the surrounding circumstances as enabler, strategy and target of resilience, to be able to set up a general framework as well as an individual company solution. Furthermore, the capabilities have been analyzed and structured with their valuable criteria:

- Agility
- Changeability
- Adaptability
- Innovativeness (short term)
- Responsiveness

The literature research provided the basics for further empirical research to understand resilience in supply chains from a company’s perspective. Further case study research grounded theory is used to practically validate the identified resilience capabilities for further use.

References

Aven, Terje (2011): On Some Recent Definitions and Analysis Frameworks for Risk, Vulnerability, and Resilience. 31 (4), S. 515–522.

Azevedo, Susana G.; Govindan, Kannan; Carvalho, Helena; Cruz-Machado, V. (2012): Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain. In: *Journal of Cleaner Production* (0).

Blackhurst, Jennifer V.; Scheibe, Kevin P.; Johnson, Danny J. (2008): Supplier risk assessment and monitoring for the automotive industry. In: *International Journal of Physical Distribution & Logistics Management* 38 (2), S. 143–165.

Blackhurst, Jennifer; Dunn, Kaitlin S.; Craighead, Christopher W. (2011): An Empirically Derived Framework of Global Supply Resiliency. In: *Journal of Business Logistics* 32 (4), S. 374–391.

Carter, Eugene (1972): “What are the risks in risk analysis? Hg. v. Harvard Business Review (Vol. 50, No. 4, pp. 72-82.).

Carvalho, Helena; Barroso, Ana P.; Machado, Virgínia H.; Azevedo, Susana; Cruz-Machado, V. (2012): Supply chain redesign for resilience using simulation. In: *Computers & Industrial Engineering* 62 (1), S. 329–341.

Carvallo, Helena; Azevedo, Susana C. (2012): Agile and resilient approaches to supply chain management: influence on performance and competitiveness. Hg. v. Springer- Verlag.

Christopher, Martin; Peck, Helen (2004): BUILDING THE RESILIENT SUPPLY CHAIN. International Journal of Logistics Management, Vol. 15, No. 2, pp1-13, 2004.

Eccles, Robert; Herz, Robert; Keegan, Mary; Phillips, David (2001): The risk of risk. In: *Balance Sheet* 9 (3), S. 28–33.

Fiksel, Joseph (2003): Designing Resilient, Sustainable Systems. In: *Environ. Sci. Technol.* 37 (23), S. 5330–5339.

Hertz, David Bendel; Thomas, Howard (1983): Risk analysis and its applications. Chichester ;, New York: Wiley.

Hofman, Debra; Aronow, Stan (2012): The Supply Chain Top 25: Raising the bar. Hg. v. Supply Chain Management Review.

Hofmann, Erik (2006): Risikomanagement in der Supply Chain.

Kaplan, Robert S.; Mikes, Anette (2012): Managing Risks: A New Framework. Hg. v. Harvard Business Review. Harvard.

Kunreuther, Howard (2006): Risk and Reaction. Hg. v. Harvard International Review.

Manuele, Fred A. (2005): Risk Assessment & Hierarchies of Control. Hg. v. Proffesssional Safety.

Manuj, Ila; Mentzer, John T. (2008): Global supply chain risk management strategies. In: *International Journal of Physical Distribution & Logistics Management* 38 (3), S. 192–223.

Norris, FranH; Stevens, SusanP; Pfefferbaum, Betty; Wyche, KarenF; Pfefferbaum, RoseL (2007): Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. Hg. v. Springer Science and Business media. Hannover.

O'Rourke, T.D (2007): Critical infrastructure, independencies, and resilience, S. 23–29.

Park, J.; Seager, T. (2013): Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems., S. Risk Analysis: An International Journal; Vol. 33 Issue 3, p356-367, 12p.

Peck, Helen (2005): Drivers of supply chain vulnerability: an integrated framework. In: *International Journal of Physical Distribution & Logistics Management* 35 (4), S. 210–232.

Pettit, Timothy J. (2008): Supply Chain Resilience:Development of a conceptual framework, an assesment tool and an implementation process. The Ohio State University.

Pettit, Timothy J.; Croxton, Keely L.; Fiksel, Joseph (2013): Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool. In: *J Bus Logist* 34 (1), S. 46–76.

Pettit, Timothy J.; Fiksel, Joseph; Croxton, Keely L. (2010): Ensuring supply chain resilience:development of a conceptual framework. In: *Journal of Business Logistics* 31 (1), S. 1–21.

Pickett, Christopher (2006): Prepare for supply chain disruptions before they hit |. Hg. v. Global Supply Chain content from Material Handling & Logistics.

Ponomarov, Serhiy Y.; Holcomb, Mary C. (2009): Understanding the concept of supply chain resilience. In: *The International Journal of Logistics Management* 20 (1), S. 124–143.

Sheffi, Yossi (2007): Building a Resilient Organization. Hg. v. National Academy of Engineers. Washington DC..

Sheffi, Yossi; Rice Jr.; James B. (2005): A Supply Chain View of the Resilient Enterprise. Hg. v. MIT Sloan Management Review.

Stewart, Geoffrey T.; Kolluru, Ramesh; Smith, Mark (2009): Leveraging public-private partnerships to improve community resilience in times of disaster. In: *International Journal of Physical Distribution & Logistics Management* 39 (5), S. 343–364.

Implications of Climate Change on Global Supply Chains

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This paper explores implications of climate change on global supply chains. Scientific findings predict that human induced climate change and global warming will bring about large scale environmental changes such as sea-level rise, flooding, extreme weather events, and heat waves with potential catastrophic consequences to industries and society. At the same time multinational organisations are becoming increasingly lean and geographically fragmented. Current management and adaptation strategies have largely excluded drastic changes in the natural environment from their approaches and communication with the scientific community has been limited. This paper argues that effects of climate change and a greater prevalence of extreme events needs to be included into supply chain design. The approach adopted involves a comprehensive literature review, expert judgements from climate experts and a case investigation with selected representatives from food and beverage industry. By integrating climate forecast provided by the scientific community into supply chain configuration theory, a conceptual framework is proposed for systematically identify and manage key sources of climatic risks in the supply chain. With a better understanding of the risks from climate change, organisations can develop resources and capabilities to avoid collapse, minimize discontinuities or even advance comparative advantage. The paper presents existing understanding on climate change, extreme weather events and risks in global supply chains.

Key words: Extreme weather, Climate Change, Food supply chain, supply chain risk

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) confirmed in 2007 that the planet´s climate is warming (Solomon et al. 2007). The effect of these changes – which are related to anthropogenic activities emitting greenhouse gases – are changes in ecosystems, distribution of water resources, and patterns of extreme weather events with subsequent damage to human health, infrastructure, and livelihoods (Parry et al. 2007). While many organisations have taken steps to reduce emissions, much fewer businesses are considering the physical risks from climate change in their structural planning (Sussman & Freed 2008). Instead, modern supply chains are becoming increasingly lean with less room for slack as managers try to run their operation with less human and physical capital (Linnenluecke & Griffiths 2010). As supply chains become globalised, they also become increasingly fragmented and geographically dispersed with less end-to-end visibility (Christopher & Lee 2004). There has also been a trend of increased collaboration among firms to compete as extended enterprises against other integrated supply chains (Spekman & Davis 2004). Accordingly, risk has become associated with the interdependence among supply chain partners.

In their assessment from 2012, the World Economic Forum lists extreme weather events as the second most significant supply chain disruption trigger after natural disasters. The rationale for this achievement can be attributed to events such as the impact of the Thailand floods in 2012 that damaged more than 10,000 factories predominantly in the high tech and automotive industries resulting in insurance claims in the excess of US$20 billion (Fogarty & Balwin 2012). In the same year, a prolonged drought hit the Midwestern United States which resulted in record low water levels on the Mississippi river, forcing transport company Cargill Inc. to operate its barges at 13 per cent below normal capacity (Plume 2012). The cost from the drought to Texas farmers have been US$2.1 billion in livestock losses and US$3.1

billion in crop losses (Reuters 2011). The exact impact from extreme weather events on supply chains remains a field of limited research (T. J. Wilbanks et al. 2007). Specifically, there is a search for literature that bridges scientific discoveries with management theory in order to understand how organisational spatial planning can be used to assess the impact from climate change to minimise uncertainty in strategy development (Linnenluecke et al. 2012). Furthermore, any advance to identify risks in supply networks needs to take a holistic approach, not overlooking essential logistic, market and human aspects (e.g.,Christopher & Peck, 2004; Manuj & Mentzer, 2008; McManus, Seville, Vargo, & Brunsdon, 2008). Climate change represents a new and somewhat daunting challenge for businesses. The issue is exacerbated by the uncertainty in projections of the distribution in temperature, precipitation and droughts (Sussman & Freed 2008). This paper will approach these issues from a supply chain configuration perspective. Critical steps in supply chain network design will serve to assess the implications of climate change on various operations.

2 Theoretical background

2.1 Supply chain configuration

The concept of supply chain configuration was considered at an early stage within strategic management as a method to align company objectives, capture market shares or take control of strategic resources (Kotter 1995; Mintzberg et al. 1998). Traditionally, configuration was viewed as a series of fixed stages, resulting from a firm´s strategy (Chandler 1962). Under this definition, the configuration would only experience periodical transformation as a response to consolidation and outsourcing of non-core operations (Porter 1985; Mintzberg et al. 1998). Example of such operations can be information services, logistics, or design activities (Tang 2006). Firms may also, for example, design their supply chain in order to take advantage of operational synergies and therefore plan their network to enhance individual capabilities by merging operations (Kandwalla 1970); to manage imbalances between supply and demand (Mason-Jones et al. 2000); or to manage uncertainty of the supply of input resources (Lee 2002).

Various frameworks are developed to determine the scope of a supply chain network (Min & Zhou 2002). One method is to look at the decision levels. This approach splits configuration into a strategic, tactical, and operational level (Stevens 1989; Chopra & Meindl 2001). In contrast, Cooper et al. (1997) suggest that network management is concerned with three closely connected elements. These are the supply chain structure, business processes, and process links. In contrast, Tang (2006), argues that supply chain network configuration is predominantly considered with the selection process of possible suppliers, manufacturing plants, delivery services and storage facilities. In their definition from 2008, Srai and Gregory emphasise on the network structure, process flow, interrelationship/governance and the value structure of the product.

Network Structure: According Lambert et al. (1998) the supply chain network structure involves the analysis of *supply chain partnerships, structural dimensions,* and *supply chain links*. Partnership analysis involves identifying the members of the supply chain that either directly or indirectly interact with the focal company (Lambert et al. 1998). *Primary members* are those that perform a job targeted towards a particular client whereas *supporting members* provide products or services used by the primary members (i.e. third party logistics supplier)(Lambert et al. 1998; Min & Zhou 2002). Partner analysis is useful in order to set the boundaries of the network.Supply chain structural dimensions refer to the tier shape and composition (Srai and Gregory, 2008). Typically, three dimensions are considered when describing and analysing supply chain structure. These are *horizontal complexity, vertical complexity,* and *location of the focal company in the horizontal plane* (Lambert et al., 1998). Horizontal complexity refers to the number of tiers while the vertical complexity describes the number of members within each tier. Sometimes it is also useful to consider the *spatial complexity* within a tier (Gardner & Cooper 2003). Strategic decisions such as moving from single sourcing to multiple-sourcing, or the engagement in frontward or backward integration, will change the appearance of the supply chain (Min & Zhou 2002).In their analysis of the structural dimensions of the supply chain, Lambert, Cooper and Pagh (1998) describe the three types of business links featured in the network based on the level of criticality to the focal company. These are *managed process links, monitored process links* and *non-managed process links*. Managed links are the most critical to the focal company, and where the focal company is actively involved. Monitored links are less critical and non-managed links are links where the focal company is not actively involved. In addition, there are *non-member links* which are links in other supply chains connected to the focal company. Decisions made in non-member links may have implications for the configuration, performance and resource allocation of the focal company (Lambert et al.. 1998). This way of categorising links provide managers with a method of limiting their analysis by focusing on the relationships most critical to the operation (Min & Zhou 2002).

Process Flow: The process flow describes "the material flow between and within operational manufacturing units and refers to all value adding and none-value adding activities" (Srai & Gregory 2008, p.394). Davenport (1993) describes a business process as "a structured and measured set of activities designed to produce a specific output for a particular customer or market." The definition puts emphasis on the coordination of activities in time and space, start and end, input resources and way of action. Other definitions emphasise the value to the consumer that stems from the transformation of inputs (Hammer & Champy 1993). Activities performed and coordinated within an organisation will foster their own unique supply chain relationships. These activities should also be considered as decisions made internally by one member will impact on the performance of other members (Håkansson & Snehota 1995).

Value Network: The value structure may refer to the composition of the product or service, its constituents, sub-assembly and replenishment modes (Srai & Gregory 2008). In the traditional value chain, value is added as the product travel from upstream partners to the end consumer. In a value network, value is co-created from the combination of members in the network (Peppard & Rylander 2006). Thus, a value network looks at how value is created and influenced in supply chain relationships (Holm et al. 1999). Other work looks at how the value can be created based on positioning options for firms in supply relationships (Huemer 2006). Finally, in their value chain architecture model, Holweg and Helo (2013) introduce risk management, buffering, and point of customisation as important elements in value creation.

Risk in Supply Chain Network: There is plenty of literature on supply chain risk management and to make a comprehensive review is beyond the scope of this paper. There are however a few papers that list risks that are of particular relevance to supply chain network design. The risks below are from Min and Zhou (2002) and was produced to highlight risks important to supply chain design modeling. These risks have also been addressed in other significant papers. Risks include:

- Quality failure; quality failure upstream can have devastating consequences due to the inter-dependence (Min & Zhou 2002).
- Risk of information failure; disruption to information flow may give rise to a bullwhip effect which can lead to imbalances of supply and demand (Kleindorfer & Saad 2005).
- Capacity constrains; Constraints can arise in supply, storage, inventory capacity, and product and information flows (Spekman & Davis 2004; Chopra & Sodhi 2004).
- Service compliance; these constraints are associated with vulnerability to inbound and outbound logistics (Svensson 2000).
- Vertical structure; the vertical structure (i.e. the number of members in a tier) has to be fit to handle upstream demand (Min & Zhou 2002).

These risks are specifically relevant when considering supply chain integration and inter-firm relations. Nevertheless, there is still a search for literature that address the implications of climate change from a network perspective. Linnenluecke et al. (2011) suggest that firms should consider the prevailing climatic conditions in any given location of their supply network. They also propose that firms make a cost benefit analysis before considering upgrading or moving parts of their operation elsewhere. Christopher and Peck (2004) suggest that supply chain network engineering should commence with an inventory analysis over the potential risks in the network together with a critical path analysis in order to advance supply chain knowledge. Other work challenge the lean concept with less slack in their supply chains (Bodin & Wiman 2007; Linnenluecke & Griffiths 2010).

2.2 Climate Change

There is broad consensus that climate change will present new challenges to businesses in terms of possible regulations for greenhouse gas emissions, changing attitudes, and evolving markets (e.g.,Cogan 2006; Mills et al. 2006). In addition, the physical effects of climate change - shifts in temperature and precipitation patterns, the prevalence of weather extremes, changes in sea level - can impact on operational procedures, physical and human assets, and access to resources (Schneider et al. 2007). In addition, managing unexpected changes in the eternal environment is often considered one of the most difficult tasks facing organisations (e.g.,Linnenluecke & Griffiths 2010). A warmer climate is expected to bring about large scale changes in natural and managed ecological systems and therefore also in socio-economic structures (Folke et al. 2002). In addition to global warming, the scientific community are also concerned with the growing trend in extreme weather events which are projected to increase in intensity, frequency and duration (Goodess, 2013; Stephenson, 2004). Climate change is expected to impact on the distribution of fresh water resources, global biogeochemical cycles, agricultural output, and ice sheets (Scheffer et al. 2001) which in turn will have impact on human health, infrastructure, buildings, energy production and distribution, transportation, supply and demand, and industrial processes (Sussman & Freed 2008).

Extreme Weather Events: Evidence suggest that climate change will increase the frequency and intensity of droughts, heat waves, heavy rainfall and tropical storms (Trenberth et al., 2007). Extreme weather events are complicated phenomena that usually involves a meteorological variable (or a combination of variables) exceeding a local threshold(s) (Schneider et al. 2007). Recent extremes such as the Thailand floods (2011), the European heat wave (2003), the winter storm Kyrill (2007) and the droughts in the American Midwest (2011) have caused extensive damage to industries and society (UNISDR 2013; Linnenluecke & Griffiths 2010). Even though individual events cannot be directly associated to climate change (France et al. 2007), it is possible to gather data on natural disasters and events that overthrow social response capabilities (Dow & Downing 2007). Records from the International Disaster Database (CRED) show that the number of severe windstorms and floods has not only increased since the 1960´s but also become greater in magnitude, more persistent, and affect a greater number of people. For the most part, projections indicate that the rate of occurrence and magnitude of weather extremes will increase.Mid-latitude continental interiors is expected to experience more frequent and more persistent temperature extremes (Ipcc 2007). Evidence also support an increase and a northward migration in tropical cyclone activity, and more extensive and longer droughts in the tropics and sub-tropics (see Appendix B) (Ipcc 2007; Webster et al. 2005). For example, in the United States, overall precipitation has increased by 5 to 10 percent over the last decade and is released in fewer more intense events. In Europe, seasonal heat waves is expected to become more common, and by 2030 Australia is projected to experience 10 to 50 percent more days over 35 ˚C (Dow & Downing 2007).

Types of extreme events and definitions: According to the IPCC (2007), a weather extreme is “an event that is rare at a particular place and time of the year.” Weather events become extreme when a meteorological variable exceed some kind of fixed threshold value or taking a maximum value (Goodess 2013; Stephenson 2008). Weather extremes are commonly attributed to one of three aspects: frequency, intensity or duration (e.g.,Linnenluecke et al. 2012). Since what is considered rare will change from one place to another, most indices are determined by using thresholds based on underlying probability distributions (e.g., the 95th or the 98th percentiles) for some kind of meteorological variable. For the most part, scientific literature will mention four types of extremes (Goodess 2013). These are:

- Extreme temperatures such as prolonged heat waves and heat spells including droughts
- Heavy precipitation which may lead to floods and mass movements (wet)
- River floods and peak discharges to due to intense warming and rapid snowmelt
- Extra tropical cyclones which are associated with high wind speeds. These are also known as hurricanes and typhoons depending on location

The IPCC (2012), also includes sea level rise in their list of extremes. They project that global mean sea levels could rise by 0.18-0.59m over the 21th century. However, this could also fall under the category of climate extremes (long term). Weather extremes are complex phenomena and much remains to be understood about their onset, distribution and development. In addition, historical data on extremes is insufficient and many regions are poorly covered, these are also the regions that would benefit the most from such forecasts (Goodess 2013).

Impacts of Extreme Events: Given the change in development of extremes, the demand for information services has been increasing (WMO 2009). Information about extremes are important because many practical problems require the knowledge of extremes - the infrastructure associated with water and energy supply, transport of goods and services - which are sensitive to meteorological variables (WMO 2009). In addition, much infrastructure (i.e. urban drainage, flood risk structures, water supply systems, ventilation and cooling) is often designed under the assumption that climate is a static phenomenon (e.g.,Wilby 2007; Meyer et al. 2005). With extreme events becoming more regular and more persistent, certain areas may no longer be viable for agricultural activities such as wine production (Jones et al. 2005), or fit for industrial activity (e.g., land that become flooded from rising sea levels) (Linnenluecke & Griffiths 2010). Extreme weather events have the power to create significant disruption to the organisational environment. The economic losses from Cyclone Larry (2006) in Australia were estimated to US$ 1.3 billion which was equivalent to 0.17% of National GDP. More than 30 percent of the losses was attributed to damage of sugar and banana production (Linnenluecke et al. 2012). For smaller nations the economic consequences of such events can be devastating. When Hurricane Mitch hit Honduras, losses were estimated at 7 percent of GDP (T. J. Wilbanks et al. 2007). These events result in significant economic setbacks and may set in motion a downward spiral in economic development (Linnenluecke et al. 2012).

Following the monsoon rains and the tropical storm Nock-Ten in 2011, more than 1000 automotive and electronics manufacturing factories were flooded in Thailand (Haraguchi & Lall 2012). Companies suffered direct losses to plant and inventories and indirectly by damaged ports, roads and railways or by power shortages (UNISDR 2013). Production for Toyota and Honda fell by 84 percent (compared to 2010) with associated losses of US$1.25 and US$1.4 billion respectively. In addition, Thailand supplies 43 percent of the world's hard disk drivers and the shortage resulted in sudden increase of global prices in hard disk drivers (Okazumi et al. 2012). According to the WMO (2009), weather extremes accounts for almost 90 percent of all natural disasters. Nonetheless, it should be noted that not all industries will lose on climate induced extreme weather. Crop yields may increase in certain areas due to longer growth periods (for example in Russia) (Stern 2007). Extreme weather will also increase the demand for certain products and services (i.e. construction sector in the aftermath of an extreme) (Sussman & Freed 2008; Metcalf & Jenkins 2005).

Industry	Potential risks from extreme weather events	Selected reference
Energy	■ Reduced hydropower potential due to loss of melt water	(Parry et al., 2007)
	■ Increased demand for cooling can result in system stresses during prolonged heat waves	(Cardell et al. 2008)
	■ Destruction to property and transmission systems from storm events	(Cardell et al. 2008)
	■ Uncertainty over supply of cooling water for power plants	(Cardell et al. 2008)
Agriculture	■ Damage to crop from insect outbreaks, pathogens and invasive species associated with prolonged heat waves	(Diaz & Markgraf 1992)
	■ Increased danger to wildfires during drought	(Parry et al. 2007)
	■ Reduced water supply for irrigation during drought	(Metcalf & Jenkinson 2005)
	■ Conflict over water resources during prolonged drought	(Howard 1997)
	■ Disruption to commercial channels from extremes may interrupt the flow of raw materials	(Metcalf & Jenkinson 2005)
	■ Inadequate training or equipment to maintain operations in excessively wet or dry conditions	(Metcalf & Jenkinson 2005)
	■ Quality of issues over grains, seeds, and prewashed products	(Metcalf & Jenkinson 2005)
	■ Land resources may be permanently or temporarily unavailable due to storm surge, sea level rise of flood	(Parry et al. 2007)
	■ Increase risk of heat morbidity of work force	(Menne 2005)
	■ Risk to animal welfare and productivity during prolonged heat waves	(Metcalf & Jenkinson 2005)
	■ Risk to product and inventory from overheating	(Metcalf & Jenkinson 2005)
Manufacturing	■ Damage to plant and premises from storms, heavy precipitation and flooding resulting in subsidence failure	(Ekstrom et al. 2005)
	■ Reduced performance of machinery due to overheating	(Metcalf & Jenkinson 2005)
Construction	■ Inadequate drainage systems to cope with heavy precipitation	(Wilby 2007)
	■ Excessive heat on construction sites will impact on processes and work force	(Menne 2005)
	■ Extreme events may change regulations and design standards	(Kirshen et al. 2006)
Insurance	■ Increased need for catastrophe models	(Metcalf & Jenkinson 2005)
	■ Increased commercial risks associated with climate sensitive products such as agriculture	(Metcalf & Jenkinson 2005)
	■ Increased risk to human health from storms, prolonged heat, flooding, and vector borne diseases	(Menne & Bertollini 2000)
Tourism	■ Change in demand for tourism	(Hamilton et al. 2005)
Mining	■ Disruption to operation from flooding of shaft	(Cheong et al. 2011)

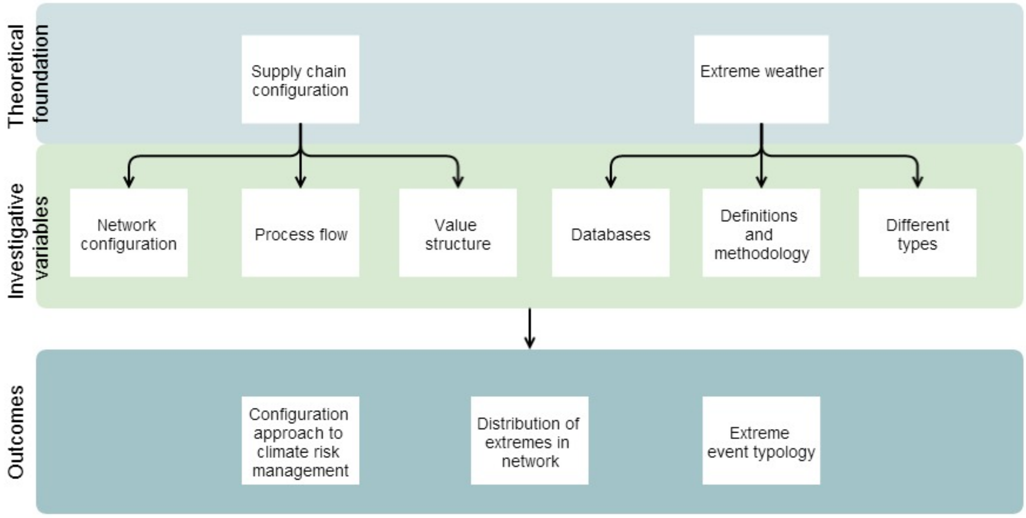
Expected changes in climate induced weather extremes suggest that many firms need to develop a more systematic approach to better recognise the potential risks associated with their organisational structure. The frequency and intensity of weather extremes are likely to lie outside organisational experience and coping capacity (Linnenluecke et al. 2012). While the literature on organisational resilience is extensive it deals for the most part with long term gradual change in the external environment (Meyer et al. 2005), and coping strategies are usually accounted for in organisational crisis management (Preble 1997). Other literature on resilience focus on how organisations can withstand disturbances but does not explicitly consider extreme weather events (Linnenluecke et al. 2012).

The research on supply chain configuration has for the most part been concerned about the level of integration, inter-firm relationships, management of risk, and ways of analysing product value.

However, these tools do also present a way of analysing the distribution and potential impact of climate related risks in the organisational network. There is still much left to understand about the development of extreme weather events and the typology in literature is fragmented. Extremes are inherently complex and there is no consistent way of classifying extreme events (e.g., Goodess 2013; Stephenson 2008; Linnenluecke et al. 2012). In addition, there is little or no guidance on where to find appropriate information about weather extremes (e.g., Linnenluecke et al. 2012). As such there is a search for literature that provides direction on ways to assess the implications from climate change on supply chain network structures.

3 Investigative Framework

With the ambition to address this gap, this study develops a conceptual framework focusing on the interaction between weather extremes and supply chain network configuration. The following questions will help direct the study: What are the type of weather extremes, their characteristics and projections in relation to climate change? How might extreme weather events affect supply chain networks?



The investigative framework behind the research question can be observed above .Configuration variables to be included in the study are network structure, process flow and value structure, all familiar from the literature review. The risks associated with climate change are represented by the threat from extremes. The paper will investigate the various types of extremes, how extremes are defined, the challenges with these definitions, and where the information about these can be found. This section has described climate change and highlighted the rationale for industries to pay attention to the development in extreme weather events. A change in the systematic nature of extremes will challenge prevailing organisational and industrial strategies, and while extreme weather events are associated with significant risks there are also opportunities for some industries to benefit from the trend. The operations management literature on climate change is limited and does not adequately encompass the challenges to industry associated with extreme events and there is a need for systematically examine the implications of these events to various industries.

4 Approach

Research approach includes a series of case studies in climate changes studies institutes and three global food manufacturers. Analysis of Case study on climate change are presented in appendix. A case study is recommended when the researcher has limited knowledge of a contemporary phenomenon as it allows him or her to study complex relationships in their natural environment thus producing a high level of contextual information (Yin 1994). A case study is also recommended when the boundaries of the phenomenon and context cannot be perfectly established. Given the nature of this study, a case study approach was considered appropriate. This study takes a predominantly exploratory approach. It is recommended to establish appropriate boundaries prior to any supply network research (Cooper et al. 1997; Srai & Gregory 2008). For this analysis, the boundaries of the network is case dependent and determined by the critical processes and the level of influence from any particular network node rather than level of ownership (Srai & Gregory 2008). Consequently, the boundaries of this research were set to capture the relevant influence from weather extremes rather than according to the level of ownership.

Organisation	Contact	Organisational capabilities/Expertise
World Meteorological Organisation	Director Christian Brondin	■ Atmosphere and ocean modelling ■ Water resources ■ Weather warning service
British Antarctic Survey	Prof. John Turner Dr. Gareth Marshall Dr. John King	■ Arctic and Antarctic Research ■ High latitude Surveys ■ Long term observations
Munich Re	Dr. Jain Eicher	■ Exposure and impact analysis
Swedish Meteorological and Hydrological Institute	Mr Weine Josefsson	■ Regional climate modelling ■ Northern Europe ■ Government services ■ Adaptation services
East Anglia University	Dr. Clare Goodess	■ Mediterranean climate modelling ■ Impact models ■ Damage to physical structures
National University of Colombia	Ass Prof. Omar Cardona	■ Socio-economic implications ■ Caribbean and South America ■ Disaster management
4CMR	Dr. Aideen Foley	■ Climate modelling ■ Policy innovations

Company	Product	Area Served	Person Responsibility	Market Position by turnover
Vegetable Producer	*Salad and vegetable products*	*United Kingdom and Europe*	*Supply Chain*	*Number 1 producer in the United Kingdom*
Brewery	*Beer, cider, soft drinks, juice, water, wine, spirits and coffee.*	*Northern Europe*	*Supply Chain*	*Top 3 in Sweden*
Dairy Producer	*Cheese, butter and milk products*	*Worldwide*	*Supply Chain*	*Number 7 in the world*

Supporting data for the cases was gathered from literature, relevant databases, and scientific journals prior to any meeting with the informants. The second part of the study presented and analysed the data. Data was collected in three stages. To begin with, information on climate change and weather extreme was collected. The second stage involved gathering information on supply chain configuration. In the final stage, information from the scientific community and the industrialists were brought together to explore the risks in the supply chain networks. The sources of information used in the study include documentation, archival records, interviews and participant observation. The format for the interviews were open-ended questions as suggested by Yin (1994). Open-ended questions expand the sources of information and depth of information and enable individuals to obtain data that may not have emerged from a survey (Oke & Gopalakrishnan 2009). Missing information was added through email correspondence. For triangulation purposes, the questions to the scientific community were the same yet flexible enough for the scientist to put emphasis on his or hers area of expertise. Scientific interviews were conducted until a point of saturation was reached and no new information was forthcoming (Eisenhardt 1989; Glaser & Strauss 1967). All documents emerging from the interviews were verified by the informants to build validity to the extent it was possible (Yin 1994).

The outcome of the scientific interviews and the desk research was introduced to the case companies. With the scenarios in front of them, the participants were encouraged to think about the possible issues related to current configuration. A number of different databases recommended by scientists (see next section) were used to show climatic projections and risk assessments for the area where the industry was located. A list of possible risks based on the literature was occasionally used as assistance. Participants were also asked to judge impact on the operation using a 1 to 5 scale (low impact to high impact) based on the weather data presented to them.

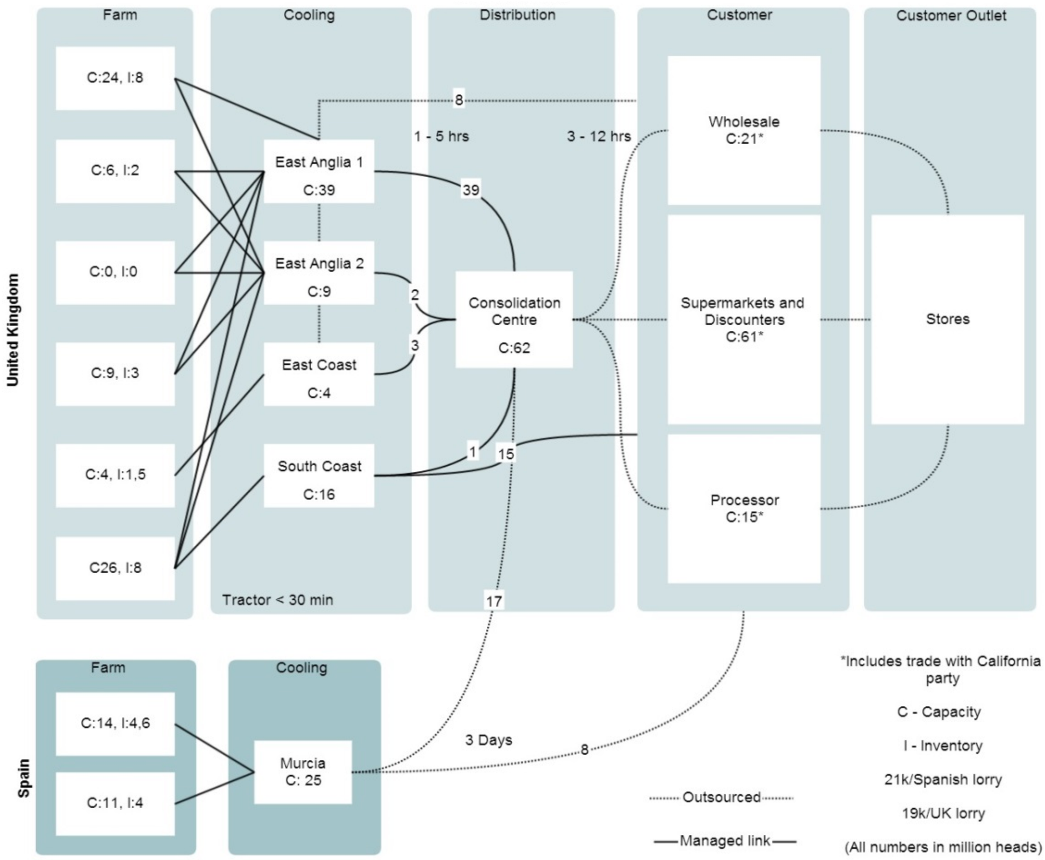
5 Case Studies

5.1 Case Study 1 : Salad and Vegetables

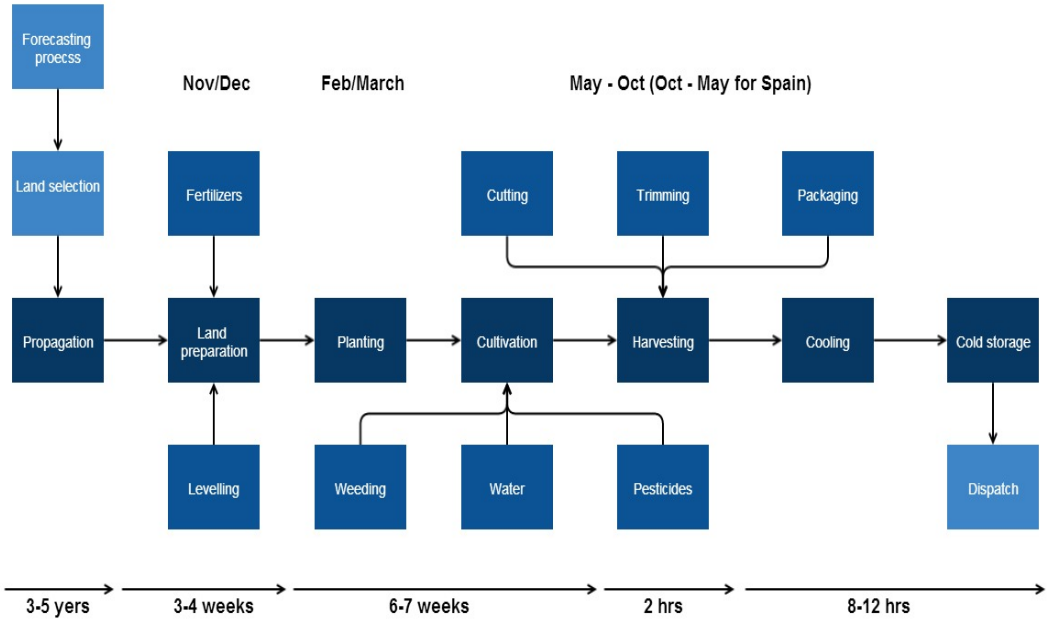
Company description: The organisation is a cooperative growing salad and vegetables. It is the biggest producer in the UK. There are 22 growers in the United Kingdom and 3 in Spain sharing 4,771 ha of crops and 1,942 ha of crops respectively. In 2012, sales were £260M and £60M in the UK and Europe respectively. Lettuce product was selected for the study. Information below is based on a discussion with the company Planning Manager.

5.1.1 Supply chain configuration analysis

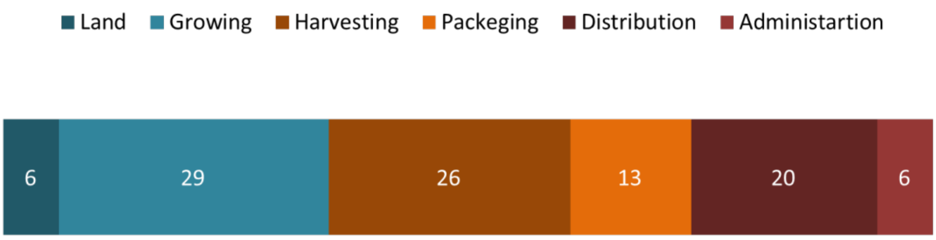
Network structure: The focal point of the analysis will be the UK consolidation centre. Lettuce is sourced from 8 growers, 6 in the UK and 2 in Spain. These are located in East Anglia, East Coast and South Coast in the UK and in the Murcia region in Spain. When the climate is not fit for harvesting in the UK the company will turn to its Spanish producer. There are three crops cycles in a year. After harvesting, the product is brought to a cooling and storage facility by tractor located no more than 30 minutes away from the fields. The majority of the product goes from cooling to customer via the UK consolidation (1 to 5 hours). The combined capacity of the consolidation centre is 62 million heads. Any gap in production will be covered by purchasing from a Californian producer. The company uses lorries to transport the product.



Process flow: The company harvest to order. Seeds are propagated while the land is prepared. Seeds are planted and cultivated under careful management. Water and pesticides are applied and weeds are removed. The company applies field harvesting which means that the product is harvested and packaged in the field before dispatch to customer or consolidation centre. Cultivation and harvesting is labour intensive and each harvesting station may carry up to 14 staff members. The process flow is shown graphically in .



Value structure: The value structure reflects the costs associated with each activity including associated taxes. Since land is relatively expensive and cultivation and harvesting requires much time and resources, much value is stored in these dimensions. Distribution can also be costly since the product must be transported from Spain during one crop cycle. Marketing (admin) is a small activity by comparison and the packaging material is relatively inexpensive.



5.1.2 Risk analysis

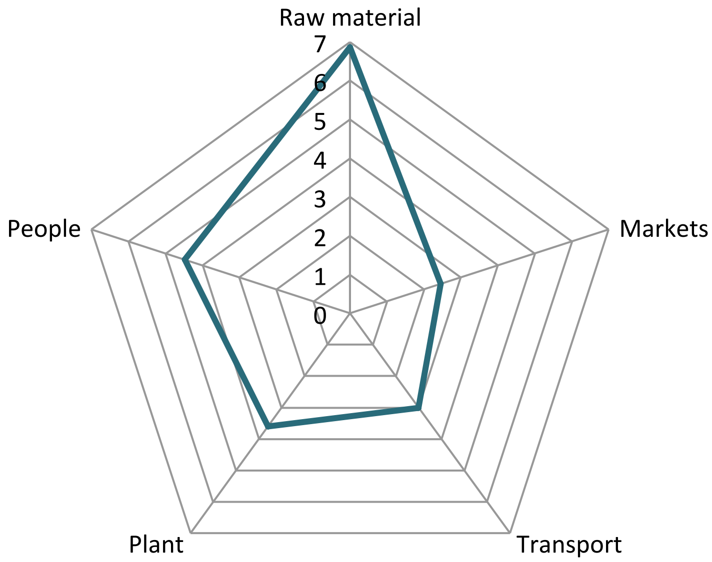
Maps from UK Met Office were used to assess risk from drought whereas DesInventar was used to assess risks from floods and storms. The results below are a combination of risks familiar from the literature and risks identified as a result of the mapping exercise.

Extreme	Risk	Domain	Probability	Impact
Drought	Reduced water availability due to long term drought	Raw material	2	4
Drought	Conflict over water resources	Raw material	1	4
Heat wave	Responsiveness to sudden change in demand	Markets	3	2
Heavy precipitation	Disruption to outbound logistics due to snow load	Transport	3	2
Drought	New investments necessary to maintain water supply	Plant	5	1
Heat wave	Seasonal labour loss due to less satisfactory working conditions	People	4	5
Heavy precipitation	Damage to product from heavy rain and hail leading to subsidence failure	Raw material	5	3
Heavy precipitation	Catastrophic loss of product from single extreme event	Raw material	5	4
Drought	Production in water stressed areas faced with stringent regulations for water use	Plant	4	2
Storm	Disruption to distribution due to port closure	Transport	3	1

Risks to Network: The operation is weather sensitive and drought is a problem for the Spanish production. The company has made considerable investment in water supply which makes the operation relatively protected in the short term (<6 months). However, longer more chronic events of dry weather, which are included in the projections for the Mediterranean region, will have an impact on production. Moreover, water management is a politically sensitive topic in Spain and future regulations of water use may put the operation at risk. The product has also experienced disruption due to heavy snow load while in transit over the Pyrenees. Lettuce from Spain has lower water content than the UK product and is therefore more durable but any delay in transit will impact on quality.

In the UK, seasonal heavy rain and droughts are of concern. Heavy rain will impact on the central growers whereas drought will be an issue for the grower in the south which is also the largest (26 million heads or 38 percent of UK production). On the demand side, the company finds it hard to respond to sudden changes associated with hot summer days when consumption goes up. Since it takes the product more than 14 hours from harvesting to dispatch the operation usually fall short under these circumstances. The company has considered expanding its operation northwards due to more favourable growing conditions but will at the same time face more risk from heavy rain.

Risks to Processes: Presently, there is no equipment to manage harvesting in extremely wet conditions without damaging the product. In contrast, prolonged heat waves in the summer will make staff working in the fields more at risk from heat morbidity. This is considered a major risk and will have profound impact on business. The company has already been forced to shorten rotations in the fields during harvesting due to extreme temperatures. In the long term, the company may therefore experience a shortage of labour as the working conditions become undesirable. The chart below show the normalised accumulated risk for the various business functions. The shape of the chart is characteristic for a climate sensitive operation that is relatively labour intensive.



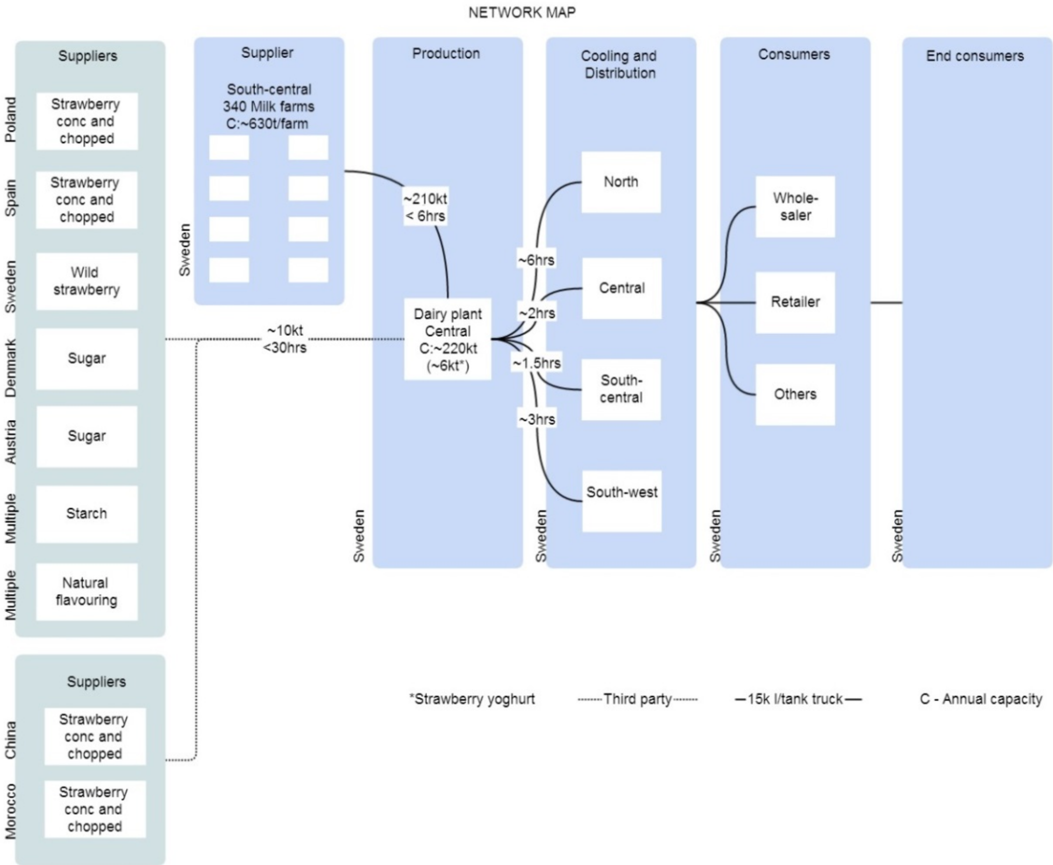
Risks to value: The biggest risks are associated with growing and harvesting. These reflect the investments made in supporting infrastructure (e.g., water supply), equipment, and labour. While these add to the costs in the short term it will make the company more resilient towards extreme events in the long term. Land is a relatively small contributor but fundamental for the operation and will indirectly add to the costs in growing and harvesting if poorly selected. For this reason the company must weigh their expansion plans towards any risks the might face.

5.2 Case study 2: strawberry yoghurt manufacturer

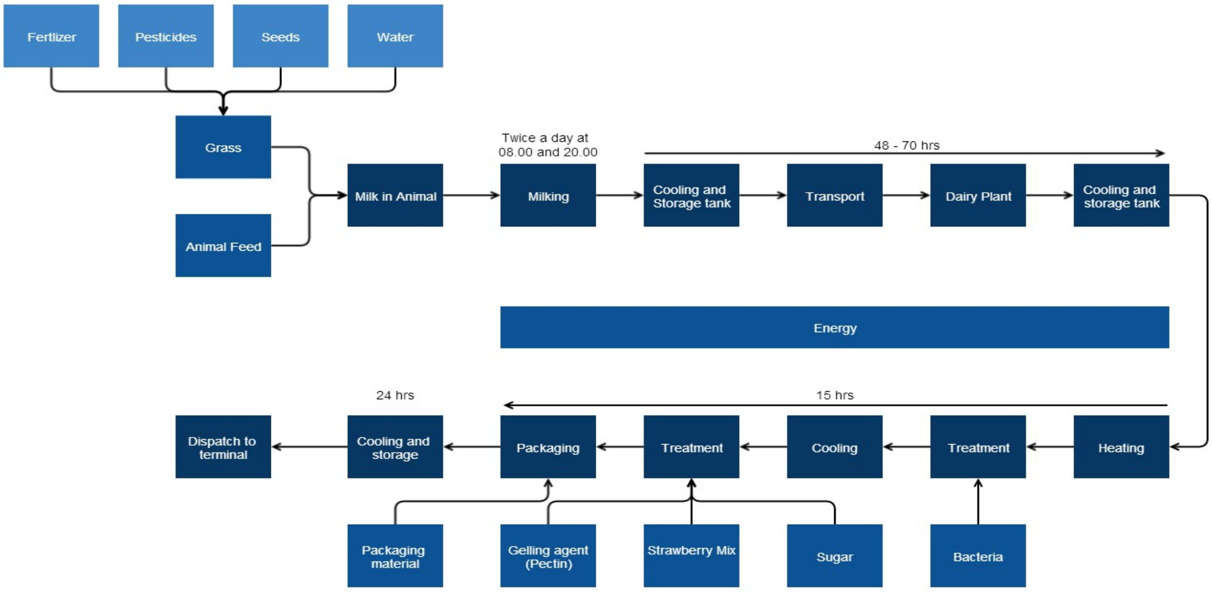
Company description: Based in Scandinavia, the cooperative is the largest producer in the region and seventh in the world in terms of revenue. The cooperative has members in Sweden, Denmark, United Kingdom, Germany, Belgium and Luxembourg. In 2011, the Swedish operation accounted for 20.4 percent of Arla´s total revenue and the 3,900 Swedish farmers represented 48 percent of total ownership. The number of employees in Sweden is about 3,500. A strawberry yoghurt product was selected for the case. Information below is based on discussions with the Quality and Environmental Manager and by a representative from the National Food Administration.

5.2.1 Supply chain configuration analysis

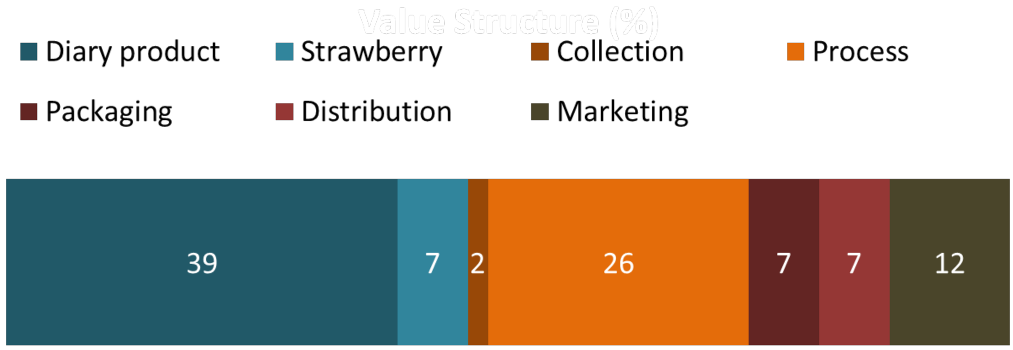
Network structure: The focal point of the supply network is the dairy plant located in Linköping, south of Stockholm. The plant receives milk from about 340 farms located within 6 hours of the plant, each capable of producing 630 tonnes of milk a year. Milk is collected by tank trucks with a capacity of 15,000 litres. Strawberry concentrate, sugar and starch are delivered from various locations in Europe, China and Morocco. Wild strawberries are supplied from south Sweden. The finished product then goes to customers via four cooling and distribution centres located in north, west, central and east.



Process flow: Animals are milked twice a day and the milk is stored in a cooling tank. Maximum temperature during storage at the farm is 4˚C for no longer than 48 hours. Milk is collected by cooling truck and kept cool during transit (maximum 8˚C) and is then transferred to another cooling tank at the plant where it is kept at a temperature of 6 to 9˚C. Trucks do not have an active cooling system and must take no longer than 12 hours to reach the plant. At the plant the milk is heated to 95˚C for 10 min and then treated with bacteria in 40˚C during 12 hours. A strawberry mix and a consistency (Pectin) are added while the product is cooled. After cooling, the product is packed and stored in another cooling plant at 6˚C for no longer than 24 hours before dispatch.



Value structure: Most of the value is located in the milk. This reflects the costs associated with the cows, farmers, equipment and land. Lorries run almost constantly which reduces cost per unit. The process at the plant is energy intensive and much value can be attributed to this stage. Finally, since the company perform a significant amount of marketing and research themselves, a substantial part of the value is associated with these activities.



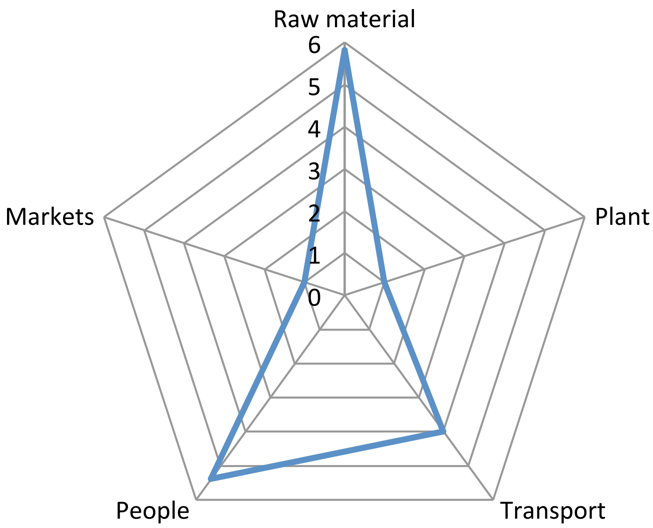
5.2.2 Risk analysis

Risk to extremes was assessed using metadata from SMHI. These maps show detailed information about the projected distribution of droughts, heavy precipitation and wind storms.

Extreme	Risk	Domain	Probability	Impact
Drought	Reduced productivity due to high temperature and poor forage quality	Raw material	3	4
Strom	Physical damage to animals from storms and heavy precipitation leading to slope instability	Raw material	1	4
Extreme temperature	Some areas may no longer be optimal for grazing due to changing conditions	Raw material	1	3
Drought	Increase in the global price of animal feed such as by-products from soya beans will add to the overall costs of production	Plant	2	1
Heavy precipitation	Increase incidence of pathogens (Alfa Toxin) in animal feed silos due to warming and precipitation	Raw material	1	5
Heavy precipitation	Loss of delivery due to heavy snow load	Transport	3	1
Extreme temperature	Damage to product when in transit between retail and households due to excessive temperature	Transport	5	1
Extreme temperature	Increase prevalence of pathogens (Bacillus cereus) due to inadequate cooling during offloading	Transport	2	3
Extreme temperature	No directions for the placement of cooling tanks at farm level	Plant	1	1
Extreme temperature	Damage to product during transport due inadequate cooling	Transport	1	2
Extreme temperature	Staff at risk from heat morbidity due to a shift in cooling from process environment to product environment	People	2	2
Extreme temperature	Drop in productivity of animals due to seasonal warming	Raw material	3	3
Extreme temperature	Shortage of drivers with adequate training	People	2	5
Drought	Loss of farmers due to decrease appeal of the profession	People	3	5
Extreme temperature	Not being able to respond to sudden demand for product	Markets	1	1

Risks to network: Risks to the network model are for the most part concentrated to the milk farms. Milk farms are located in southern Sweden which is projected to face more droughts. This will impact on forage quality and therefore on animal productivity. Some areas may therefore be less optimal for grazing. In addition there has been an incidence of Alfa toxin in animal feed and Arla is concerned how prolonged heat waves will affect the spread of toxin-producing bacteria. The manager had no information regarding the supply of wild strawberries but these are likely to be at risk if droughts are to become larger in scale and longer in duration. There has been some loss of product due to heavy snow load but the impact on overall business is low. Since the product is heat sensitive, the company has expressed some concern for a drop in demand during extremely hot weather.

Risks to processes: The vast majority of risks are associated with the cooling chain. At farm level the risks are associated with the cooling tanks and the seasonal productivity of the animals. The technical specifications for the cooling tanks at farm level state that these can endure a maximum temperature of 32˚C which puts them at risk from prolonged heat waves. In addition, there are no specifications on how these tanks should be placed. Optimal production temperature for cows is -12˚C and there is usually no cooling in Swedish farms which forces production down during the summer. With more prolonged heat waves, Arla foresee a more substantial decline in seasonal production. The production environment is also sensitive to heat and during the hot summer days of 2010, cooling was shut down in a sister plant in favour of milk production which impacted on staff working conditions. There are a number of risks to the cooling chain linked to the transport. Tank trucks that run between farm and plant do not possess an active cooling system which put the product at risk while in transit if there is a delay. Arla may also experience a shortage of drivers with the adequate training to manage milk in hot weather during summer holidays. Substantial risk of recontamination has been identified during offloading at retail docking stations when there is congestion (Bacillus cereus may grow if milk is exposed to 15 to 25˚C for four hours). Finally, there is substantial risk while in transit from retailer to households, especially during hot summer days when groceries are left in hot cars. In the long term, the company is concerned with the poor appeal of the farming profession. The above discussion is represented graphically below and reflects the concerns associated with the cooing chain.



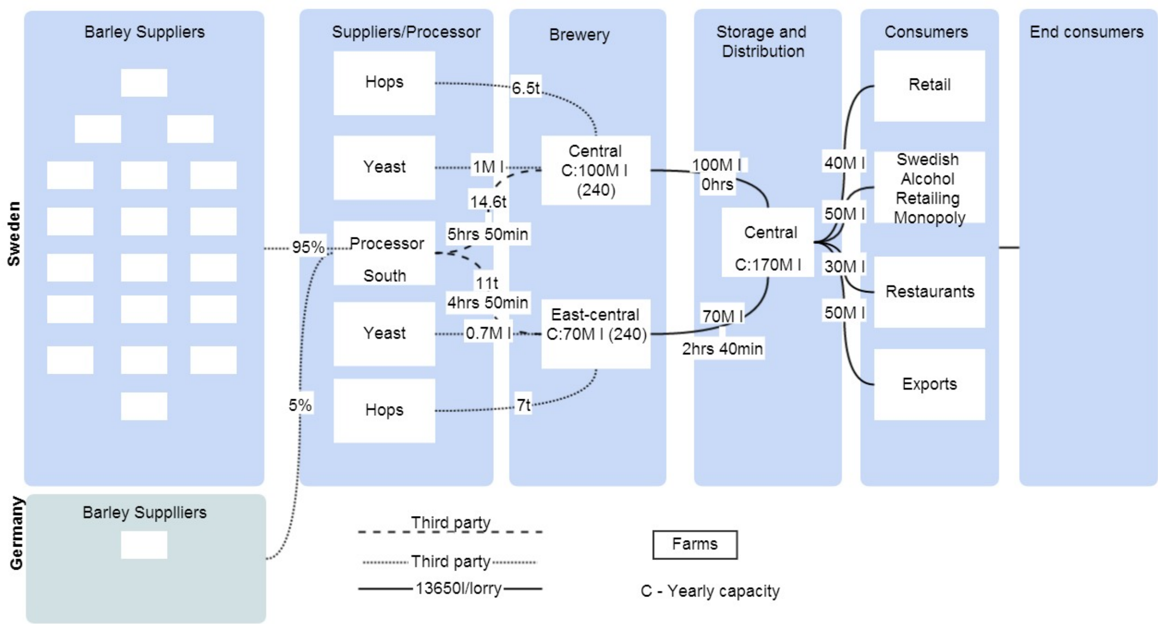
Risks to value: Most of the value is concentrated to the milk product and the process. In this value structure milk represents land, cows and other inputs. There is thus a substantial risk for value destruction at this end from droughts and prolonged heat waves. Accordingly there is some correlation of risk and value. On the other hand, the cooling chain is distributed across all functions and these risks are not well represented by the value structure. For example, distribution holds relatively little value to the consumer but an essential step in business operation and holds substantial risk. A case of recontamination, for example, can have devastating effects on reputation. Should this occur further upstream, i.e. in the process environment, then the impact will be more severe as this is likely to include a whole product line rather than just an individual delivery.

5.3 Case Study 3: Brewery Company

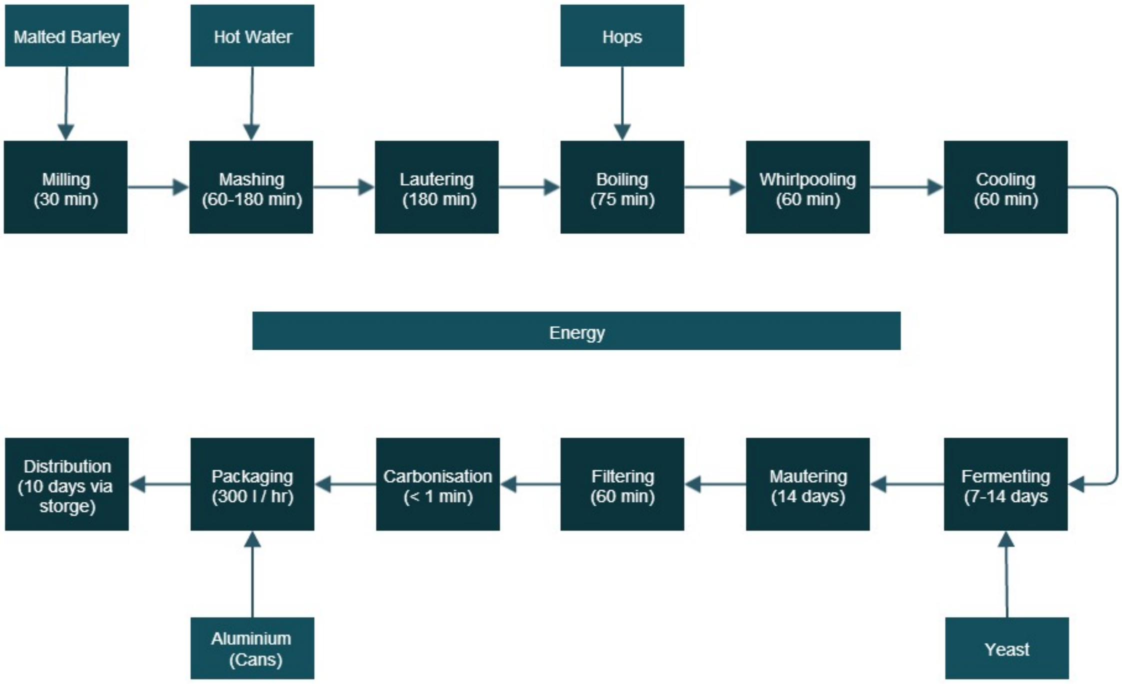
The brewery is one of the three largest in Sweden. It currently employs about 1,000 people and total revenue in 2011 was about £300M. The company has four breweries in total. Apart from beer the brewery also produces bottled water and soft drinks. Common lager was chosen for the study. Information was provided by the Corporate Social Responsibility Manager with the occasional support of a Process Manager.

5.3.1 Supply chain configuration analysis

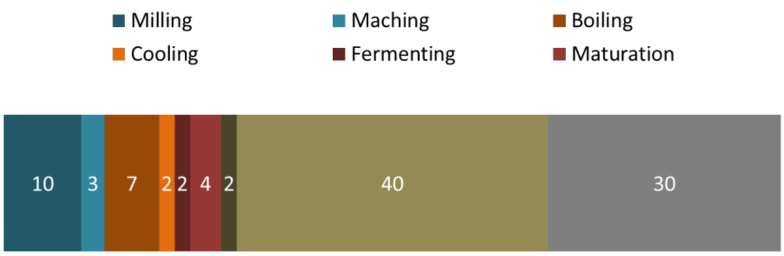
Network structure: The focal points are the breweries located near Stockholm (east-central) and Grängesberg (central). There are an unknown number of farms that supply barley to a grain processor in Halmstad (South Sweden). 95 percent of this barley comes from Swedish farmers; the remaining 5 percent comes from Germany. Yeast and hops are supplied in small quantities (yeast will be grown by the brewery itself). The brewery can process 240M litres of beer annually if necessary without interfering with other production. The central brewery and the east-central brewery produce 100M litres and 70M litres of beer respectively. From a distribution centre the product is distributed to retailers (~25%), the Swedish Alcohol and Retailing Monopoly (~30%), restaurants (~15%) and other exports (~30%). A lorry carrying canned beer can transport 15,000 litres.



Process flow: The company produces to forecast. The first step is milling of the malted barley arriving from the processor. Hot water is added in the mashing process before lautering. The hops are added during boiling. The product is filtered quickly before it is cooled in preparation for fermentation. During fermentation the yeast will multiply 3 to 5 times. This may take up to two weeks. The product is then held for 14 days to refine the flavour. The product will be filtered once more before packaging and dispatch. This product is using aluminium as packaging material.



Value structure: 70 percent of the product value is associated with packaging and distribution. The reason for this value concentration is the aluminium. Distribution is also a costly activity compared to processing. Malting of barley involves steeping (barley is soaked with water), germination and kilning (drying). These processes are captured in milling and are reflected by the considerable value in this activity. The value of other processes is linked with the amount of energy required. Lautering, whirl pooling and carbonization has a combined value of less than 1 percent.



5.3.2 Risk analysis

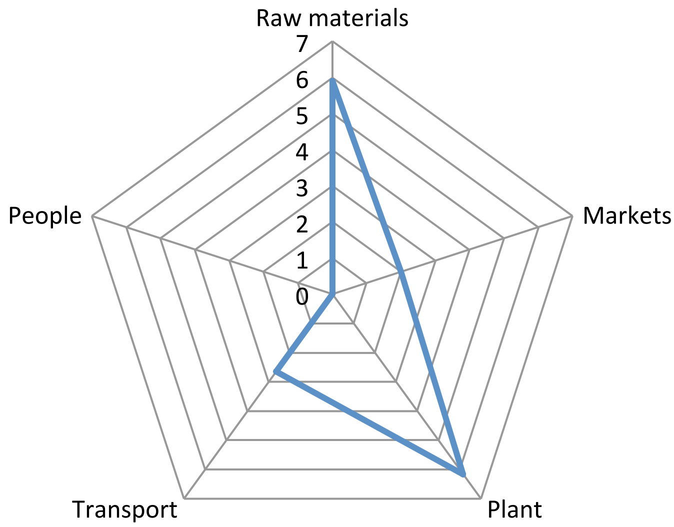
Risks were assessed using SMHI metadata and data from the UK Met Office. The format for the analysis is the same as above.

Extreme	Risk	Domain	Probability	Impact
Heavy precipitation	Global rise in the price of metals such as aluminium due to rise in global market prices	Raw materials	2	4
Drought	Fluctuating cost of malt as a resultl of global shortage due to catastrophic event such as drought	Raw materials	3	4
Drought	Fluctuating quality of barley and prewashed products	Raw materials	3	4
Extreme temperature	Changes in seasonal demand for products	Markets	2	2
Extreme temperature	Sudden change in regulations for energy use in process environment and transports.	Plant	2	2
Extreme temperature	Sudden change in regulations for energy use in processes environment and transports	Plant	2	2
Extreme temperature	Sudden change in regulations for energy use in processes environment and transports	Transport	2	2
Heavy precipitation	Public scrutiny in media due to discharge of cans into the environment from flooding event.	Plant	2	3
Heavy precipitation	Discharge of contaminants and waste water from flooding event	Plant	2	3
Heavy precipitation	Poor water quality due to agricultural discharge will add to costs of purification	Plant	2	3
Heavy precipitation	Catastrophic loss of product from single extreme event	Raw materials	3	1
Drought	Production in water stressed areas faced with stringent regulations for water use	Plant	3	4
Storm	Disruption to distribution due to port closure	Transport	3	1

Risks to network: The company is concerned over an increase in the global price of aluminium which is set by the world market and may come in short supply during an extreme event. The quality and supply of barley is at risk from climate change in two ways. Firstly, extreme weather such as drought will directly impact on the supply and quality of grains. Secondly, with population increase, the land available for agricultural production will become scarce. Beer consumption is usually associated with warm weather. Thus an increase in temperature may benefit the company whilst seasonal heavy precipitation may have the opposite effect. The brewery is less concerned with these effects and foresees a relatively stable demand.

Risks to processes: The production process is energy and water intensive. There is some concern that climate change induced extreme weather will spur a sudden change in regulations for energy use in processes and transports. This will directly affect the cost of production. In the long run, regulations may benefit the company since most of the materials are sourced locally. The company is also somewhat concerned about poor water quality as a result of agricultural discharge as a consequence of heavy precipitation and there may be a future need to enhance purification processes.

Heavy precipitation and floods may also impact on the brewery itself and result in discharge of contaminants into the environment. On the consumer end, flooding may imply that more cans end up in the environment. Poor waste management in both processes and consumer use may thus give rise to stricter consumption regulations. There have been occasional disruptions to transport from heavy snow load but these are of low concern as the community is well prepared to deal with such circumstances. Accordingly, most risks are associated to processes and raw material and waste which can be observed by the chart below.



Risks to value: The majority of the value is stored in the packaging material and in the distribution. Accordingly, an increase in world prices of aluminium and more stringent regulations for transport would be transmitted to consumers through these channels. Consumers may also be affected though an increase in energy prices and a shortage of barely which would add to the costs of production.

6 Discussion and conclusion:

6.1 Extreme weather events

The case studies reveal that supply chain networks potentially face a variety of risks from climate induced extreme weather. Extreme events are events that occupy the tails in probability distributions for meteorological or climatological variables. Prolonged heat waves, heavy precipitation, severe wind storms and floods are examples of extreme events. The severity of an extreme event will largely depend on organisational exposure and vulnerability. Since climate change will impact on the underlying conditions responsible for extremes, organisations are advised to make an inventory of potential risks to their supply network. In doing so, organisations should take a holistic approach to the value chain, whilst not overlooking essential supporting services or underestimating the threat from chronic extremes which may have serious socio-economic implications and thus affect the company indirectly.

The case study results demonstrate how supply chain configuration theory can be applied to analyse the risks from the climate change induced extreme conditions. Practitioners can observe with meaningful clarity the effects to their supply chain architecture and operational sequence. More detailed analysis is required to understand the impact to specific locations and processes but some preliminary findings are worth emphasising. The table below summarises the findings.

Level of analysis	Vegetable producer	Dairy producer	Brewery
Network structure	▪ *Reduced water availability among Mediterranean growers* ▪ *Possible conflict over water sources* ▪ *Crops may no longer be viable in new conditions* ▪ *Changes in regional patterns of production in the UK* ▪ *Responsiveness to sudden demand* ▪ *Damage to UK product from singe precipitation extreme*	▪ *Changes in locations optimal for grazing* ▪ *Increase in global prices of animal feed* ▪ *Increased prevalence of pests and pathogens* ▪ *Physical damage to animals from storms* ▪ *Shortage of farmers in the long run*	▪ *Global price increase in raw materials leading increased capital costs* ▪ *Changes in regional patterns of production* ▪ *Fluctuating quality of barley* ▪ *Increase in cost of barley supplier leading to higher prices of inputs* ▪ *Changes in seasonal demand*
Process flow	▪ *Seasonal labour loss due to undesirable working conditions* ▪ *Inadequate training or equipment to manage product in new conditions* ▪ *Increased prevalence of heat morbidity* ▪ *Disruption to transport due to heavy snow load*	▪ *Damage to product from excessive temperature while in transit* ▪ *Increased cooling to maintain performance in process environment* ▪ *Decreased comfort of internal environment* ▪ *Los of delivery due to heavy snow load* ▪ *Shortage of drivers that can manage product*	▪ *Discharge of contaminated water from production* ▪ *Reduced water quality due to discharge from agricultural land* ▪ *Disruption to transport from heavy snow load* ▪ *Sudden change in regulations for water and energy use*
Value structure	▪ *Value loss during growing* ▪ *Value loss during harvesting*	▪ *Value loss to dairy product* ▪ *Value loss in cooling chain*	▪ *Value loss in packaging material* ▪ *Value loss from energy and water purification*

6.2 Supply chain implications

Regional patterns of production: Climate change induced extreme weather will change regional patterns of optimal production. Prolonged droughts and water scarcity will make certain rain fed crops unfit for cultivation (i.e. parts of the Mediterranean). As might be expected, there seems to be some correlation between the degree of spatial and horizontal complexity and exposure as demonstrated by the lettuce case. Nevertheless, with more localised production, the organisation becomes vulnerable to regional extremes. The impact of climate change will not evenly spread geographically and many organisations may want to revise their long term expansion plans with new climatic information. The lettuce case demonstrates that organisations exposed areas may gain competitive advantage by investing in appropriate supporting infrastructure (i.e. water reservoirs and irrigation systems) rather than reconfiguring their supply chain.

Transport and distribution: Transport and distribution are critical elements for most organisations. For agricultural producers, risks are associated with the cooling chain and many producers may be forced to make additional investments in cooling facilities (including the transport and management of livestock). This may imply the establishment of new business links with third party service companies, the elimination of process steps, or a change in product packaging material (i.e. a new type of milk cartoon). Organisations may also have to consider alternative transport routes due to seasonal precipitation events or make new investments in their vehicle fleet.

Processes: With changing conditions, staff and equipment may no longer be adequate to manage the product. This is particularly true for climate sensitive crops with a longer cultivation period such as the lettuce product which has a fixed harvesting period. Certain process steps may require considerable investments or a change in procedures to enhance performance. The process environment, including staff, will be affected by climate change in a number ways. Storage and inventory may be exposed to overheating or excess humidity. The case studies demonstrated to some extent that products with short shelf life are more sensitive to weather extremes (i.e. lettuce and yoghurt). For some processes, certain machinery might be heat sensitive and will experience reduced performance during prolonged heat. The workforce is perhaps the most important component of production and will be at risk from heat stress and heat stroke which in turn will result in lower performance. Both the vegetable producer and the dairy producer have experienced health related issues. Heat stress also impacts on livestock that tend to produce less during warm conditions. This implies that management of heat may become a critical organisational capability. The process environment is also sensitive to heavy precipitation and flooding which may impact on organisational waste management and result in discharge of contaminants.

Inputs to production: Input resources such as energy, water supply, packaging material or fresh produce may become short in supply or of poor quality. These links may not be managed directly by the company and prices of essential inputs may be set by the world market (see brewery case).

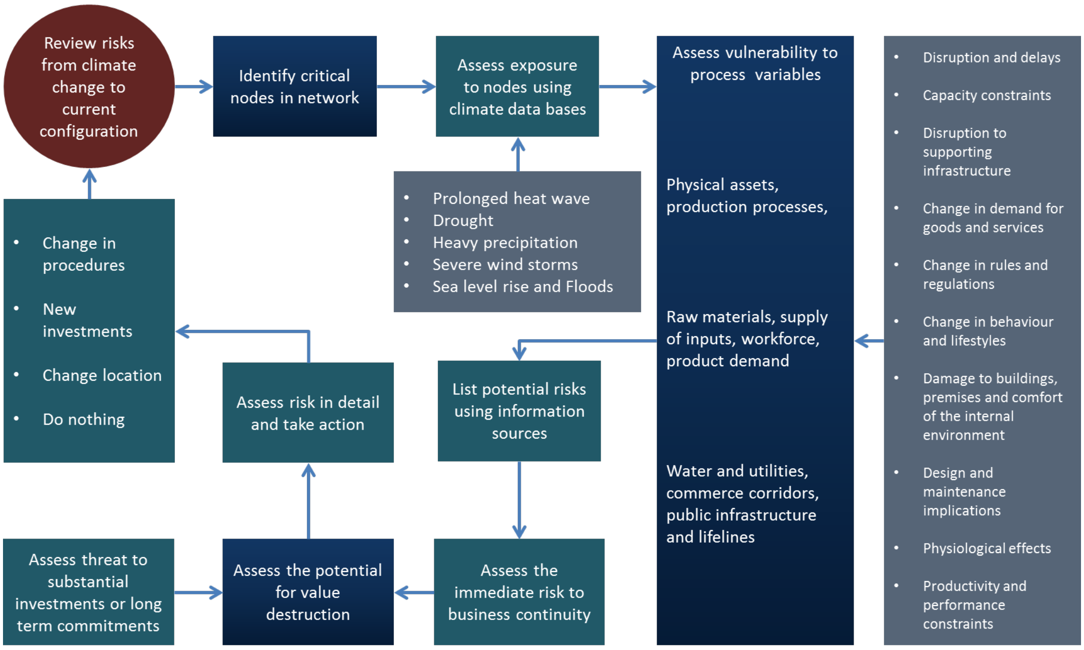
Market demand: Climate induced extreme weather will also affect the demand for certain goods and services and many organisations may find it hard to respond to sudden changes in consumer preferences. Companies that are familiar with such issues may therefore have to reconfigure their supply chain to manage such changes (e.g., more cooled storage facilities closer to customers). Extreme weather will also impact on product characteristics. Organisations that have considered weather extremes in their product design may find themselves in a superior position. The vegetable producer, for example, has noted that their Spanish product, due to lower water content, manages heat better than its UK counterpart. Thus, extreme weather events give organisations the opportunity to develop new products. This implies that organisations should develop a closer relationship with their consumers to find out how extreme weather will affect their business model.

Regulations: Finally, climate change induced extreme events could also motivate the implementation of rules and regulations to manage waste, water and energy which may impact on the design of industrial processes.

The above list is by no means exhaustive but does provide an illustration of potential risks. The below framework provides a more general approach for businesses to assess the risks from climate induced extreme weather to their supply network.

6.3 Risk assessment framework

The framework takes a supply chain configuration approach and suggests that practitioners start with identifying critical nodes in their supply chain network. Information on climate risks for critical nodes can be assessed using the recommended data sources. Exposure is then determined by the portfolio of assets located in the environment under consideration. A list of potential risks can be assembled by conducting a sequential assessment of all the processes involved. Critical process steps can be considered based on their value structure. The informant then has to decide whether to act or do nothing. Possible actions can be to change procedures, invest in new assets or supporting infrastructure, or change location.



The approach is expected to improve supply chain end-to-end visibility and help foster a better understanding of the climate risks associated with each step of the operation. Likewise, the approach may also help the practitioner to identify leverage points and market opportunities.

6.4 Key findings

Extreme weather events are complex phenomena and many organisations should be concerned about their development. Evidence suggests that climate change will increase the intensity, frequency, duration and spatial distribution of extreme events. Chronic extremes are sustained periods of climate variability. These events are less abrupt but may have significant socio-economic implications and therefore impact on organisations indirectly.

This study has shown that climate change induced weather events – prolonged drought, extreme temperatures, severe wind storms, and floods – will impact on supply chains at all levels.

- At the network level, extreme events may change patterns of optimal production, disrupt transports, impact on the supply of inputs to production, and modify consumer preferences.
- At the process level extreme temperatures may inflict on the health of workers, the performance of certain machinery, and inventory. Floods have the power to severely damage production facilities, including the management of waste.
- If not carefully monitored, extreme events have the potential to alter the value structure of the product by increasing the cost of production.

By taking a supply chain network configuration approach, organisations are provided with a systematic way of identifying not only risks, but also possible opportunities that emerge with climate change. Climate change has a direct effect on supply chains via the effects of extreme weather events and should be an integral component of supply chain network design. Not all organisations will have to consider climate information in the short term but all should be aware of the potential future threats from climate change. Those most at risk are organisations with supply chains facing substantial capital investments, those industries where climate is a critical element of production such as agriculture, and those that rely heavily on transport.

Climatic risks will not be uniformly distributed and will depend on the incidence of extreme weather events such as extreme temperatures, heavy precipitation or severe wind storms. The risk towards these extremes has to be assessed against critical supply chain nodes where core processes, supply of raw materials, markets, or other functions of the network are located. Assessing the risks to climate change involves taking a holistic approach to organisational activities including processes, value network, public services, and the competitive environment. The method developed in this paper suggests that businesses start with taking a high level approach. This type of screening will identify the most important risks to the supply chain network and signify whether further analysis is needed. The approach will place climate related risks and uncertainties within the same framework as other long term plans concerning the supply chain network. As a result of the analysis, organisations may decide to make new investments, change procedures or pull out of a location.

The research has been exploratory in nature and future research should arguably try and incorporate a greater variety of industries and perform a more detailed analysis of critical process steps. The study suffered from the fact that only a limited number of industrial representatives could take part in the study and future work should try and involve staff from multiple departments (i.e. finance and HR). The analysis would benefit from case studies with companies represented in tropical countries, regions of lower economic development, and with different configuration arrangements. It would also be interesting to try and quantify the impact by running a simulation in collaboration with representatives from the scientific community who would be able to provide more detailed knowledge about the effects from extremes locally.

References:

Acia, A.C.I.A., 2005. *Arctic Climate Impact Assessment - Scientific Report*,

Australia's coal mines hit by heavy rains, flooding | Reuters. *Reuters*. Available at: http://uk.reuters.com/article/2013/01/28/australia-floods-coal-idUSL4N0AX5MC20130128 [Accessed August 23, 2013].

Barker, T., 2007. Climate Change 2007 : An Assessment of the Intergovernmental Panel on Climate Change. , (November), pp.12–17.

Belle, N. & Bramwell, B., 2005. Climate Change and Small Island Tourism: Policy Maker and Industry Perspectives in Barbados. *Journal of Travel Research*, 44, pp.32–41.

Bodin, P. & Wiman, B., 2007. The usefulness of stability concepts in forest management when coping with increasing climate uncertainties. *Forest Ecology and Management*, 242, pp.541–552.

Cannell, M.G.., Palutikof, J.. & Sparks, T.., 1999. Indicators of Climate Change in the UK. *DETR*, p.87.

Cardell, J. et al., 2008. The electric power industry and climate change: U.S. research needs. *2008 IEEE Power and Energy Society General Meeting Conversion and Delivery of Electrical Energy in the 21st Century*.

Chandler, A.D., 1962. *Strategy and Structure*,

Cheong, Y.W. et al., 2011. Water quality changes of a closed underground coal mine in Korea. *Environmental Monitoring and Assessment*, pp.1–10.

Chopra, S. & Meindl, P., 2001. *Supply chain management: Strategy, planning, and operation*, Saddle River, NJ: Prentice-Hall.

Chopra, S. & Sodhi, M.S., 2004. Managing Risk To Avoid Supply-Chain Breakdown. *MIT Sloan Management Review*, 46, pp.53–62.

Christopher, M. & Lee, H., 2004. Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management*, 34(5), pp.388–396. Available at: http://www.emeraldinsight.com/10.1108/09600030410545436.

Christopher, M. & Peck, H., 2004. International Journal of Logistics Management , Vol. 15, No. 2, pp1-13, 2004. , 15(2), pp.1–13.

Cogan, D.., 2006. *Corporate Governance and Climate Change: Making the connection*, Boston, MA. Available at: http://www.c2es.org/docUploads/Ceres -- Corporate Climate Change Ranking 2006.pdf.

Cooper, M.C., Lambert, D.M. & Pagh, J.D., 1997. Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management*, 8, pp.1–14.

DaimlerChrysler Says Storm Will Cut Profit. *New York Times*. Available at: http://www.nytimes.com/1999/10/01/business/daimlerchrysler-says-storm-will-cut-profit.html [Accessed August 23, 2013].

Drought costs Texas farms record $5.2 billion - Weather - msnbc.com. *NBC News*. Available at: http://www.nbcnews.com/id/44177536/ns/weather/t/drought-so-far-cost-texas-farms-record-billion/ [Accessed August 23, 2013].

D'Souza, R.M. et al., 2004. Does ambient temperature affect foodborne disease? *Epidemiology Cambridge Mass*, 15, pp.86–92.

Davenport, T.H., 1993. *Process Innovation: Reengineering Work through Information Technology [book review]*,

Diaz, H. & Markgraf, V., 1992. *El Nino: Historical and Paleoclimatic Aspects of the Southern Oscillation*,

Donovan, J., 2005. BP spells out losses from hurricanes – Royal Dutch Shell plc .com. Available at: http://royaldutchshellplc.com/2005/10/05/bp-spells-out-losses-from-hurricanes/ [Accessed August 26, 2013].

Dow, K. & Downing, T.E., 2007. *The Atlas of Climate Change: Mapping the World´s Greatest Challenge* Myriad Edi. J. King et al., eds., Brighton: Earthscan.

Eisenhardt, K.M., 1989. Theories from Case Study Research. *Academy of Management Review*, 14, pp.532–550.

Ekstrom, M. et al., 2005. New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 2. Future estimates and use in impact studies. *Journal of Hydrology*, 300, pp.234–251.

Few, R. et al., 2004. Floods, health and climate change: A strategic review. *East*, p.138 pp.

Fleury, M. et al., 2006. A time series analysis of the relationship of ambient temperature and common bacterial enteric infections in two Canadian provinces. *International Journal of Biometeorology*, 50, pp.385–391.

Fogarty, D. & Balwin, C., 2012. Insight: Flood risk rampant across Asia's factory zones | Reuters. *Reuters*. Available at: http://www.reuters.com/article/2012/07/22/us-insurance-floods-asia-idUSBRE86L0GR20120722 [Accessed August 23, 2013].

Folke, C. et al., 2002. Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. *AMBIO: A Journal of the Human Environment*, 31(5), pp.437–440. Available at: http://dx.doi.org/10.1579/0044-7447-31.5.437 [Accessed August 10, 2013].

France, P.B. et al., 2007. Understanding and Attributing Climate Change.

Gardner, J.T. & Cooper, M.C., 2003. Strategic Supply Chain Mapping Approaches. *Journal of Business Logistics*, 24, pp.37–64.

Glaser, B.G. & Strauss, A.L., 1967. *The discovery of grounded theory*,

Goodess, C.M., 2013. How is the frequency, location and severity of extreme events likely to change up to 2060? *Environmental Science & Policy*, 27, pp.S4–S14. Available at: http://www.deepdyve.com/lp/elsevier/how-is-the-frequency-location-and-severity-of-extreme-events-likely-to-t9qpy1HflS/fulltext [Accessed August 10, 2013].

Håkansson, H. & Snehota, I., 1995. *Developing Relationships in Business Networks*, London: Routledge.

Hamilton, J.M., Maddison, D.J. & Tol, R.S.J., 2005. Effects of climate change on international tourism. *Climate Research*, 29, pp.245–254.

Hammer, M. & Champy, J., 1993. *Reengineering the Corporation: A Manifesto for Business Revolution*,

Haraguchi, M. & Lall, U., 2012. Flood Risks and Impacts. Future Research Questions and Implications to Private Investment Decision-Making for Supply Chain Networks.

Hassan, R., Scholes, R. & Ash, N., 2005. *Ecosystems and Human Well-being : Current State and Trends , Volume 1*,

Holm, D.B., Eriksson, K. & Johanson, J., 1999. Creating value through mutual commitment to business network relationships. *Strategic Management Journal*, 20, pp.467–486.

Holweg, M. & Helo, P., 2013. Defining value chain architectures: Linking strategic value creation to operational supply chain design. *International Journal of Production Economics*, pp.1–9. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925527313002855 [Accessed August 9, 2013].

Howard, P., 1997. Environmental undertones of war. *WWF Features January 19973 pp*.

Huemer, L., 2006. Supply Management. *Long Range Planning*, 39(2), pp.133–153. Available at: http://linkinghub.elsevier.com/retrieve/pii/S002463010600015X [Accessed August 9, 2013].

Ipcc, 2012. *Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*,

Ipcc, I.P.O.C.C., 2007. *Climate Change 2007 - The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC*,

Johnson, G.. & Malucci, L., 1999. Shift to supply chain reflects more strategic approach. *APICS-The Performance Advantage*, pp.28–31.

Jones, G. V et al., 2005. Climate change and global wine quality. *Climatic Change*, 73, pp.319–343.

Kandwalla, P.., 1970. The Effect of the Environment on Organizational Structure of the Firm. *Carneige-Mellon University, Pittsburgh, PA*.

Kate, P. Ten, 2011. Thailand's surreal industrial park: crocodiles but no chips | Reuters. *Reauters*. Available at: http://www.reuters.com/article/2011/11/24/uk-thailand-floods-hana-idUSLNE7AN02C20111124 [Accessed August 23, 2013].

Kirshen, P., Ruth, M. & Anderson, W., 2006. Climate's long-term impacts on urban infrastructures and services: the case of Metro Boston. *Climate Change and Variability Impacts and Responses*, pp.190–252.

Kleindorfer, P.R. & Saad, G.H., 2005. Managing Disruption Risks in Supply Chains. *Production and Operations Management*, 14, pp.53–68.

Kotter, J., 1995. Leading change - why transformation efforts fail. *Harvard Business Review*, 73, pp.59–68.

Lambert, D.M., Cooper, M.C. & Pagh, J.D., 1998. Supply Chain Management: Implementation Issues and Research Opportunities. *The International Journal of Logistics Management*, 9, pp.1–20.

LCCP, 2002. *LCCP (London Climate Change Partnership) London`s Warming: The Impacts of Climate Change on London*, London.

Lee, A.S., 1991. Integrating Positivist and Interpretive Approaches to Organizational Research. *Organization Science*, 2, pp.342–365.

Lee, H.L., 2002. Aligning supply chain strategies with product uncertainties. *California Management Review*, 44, pp.105–119.

Lin, C.-W.R. & Chen, H.-Y.S., 2003. Dynamic allocation of uncertain supply for the perishable commodity supply chain. *International Journal of Production Research*, 41, pp.3119–3138.

Linnenluecke, M. & Griffiths, A., 2010. Beyond Adaptation: Resilience for Business in Light of Climate Change and Weather Extremes. *Business & Society*, 49(3), pp.477–511. Available at: http://bas.sagepub.com/content/49/3/477.short [Accessed August 10, 2013].

Linnenluecke, M.K., Griffiths, A. & Winn, M., 2012. Extreme Weather Events and the Critical Importance of Anticipatory Adaptation and Organizational Resilience in Responding to Impacts. *Business Strategy and the Environment*, 21, pp.17–32.

Linnenluecke, M.K., Stathakis, A. & Griffiths, A., 2011. Firm relocation as adaptive response to climate change and weather extremes. *Global Environmental Change*, 21, pp.123–133.

Mader, T. et al., 2009. Potential climate change effects on warm-season livestock production in the Great Plains. *Climatic Change*, 97, pp.529–541.

Manuj, I. & Mentzer, J.T., 2008. Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management*, 38, pp.192–223.

Mason-Jones, R., Naylor, B. & Towill, D., 2000. Lean, agile or leagile? Matching your supply chain to the marketplace. *International Journal of Production Research*, 38, pp.4061–4070.

McManus, S. et al., 2008. Facilitated Process for Improving Organizational Resilience. *Natural Hazards Review*, 9(2), pp.81–90. Available at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)1527-6988(2008)9:2(81) [Accessed August 23, 2013].

Menne, B., 2005. Extreme Weather Events: What can We do to Prevent Health Impacts? In *Extreme Weather Events and Public Health Responses*. pp. 265–271.

Menne, B. & Bertollini, R., 2000. The health impacts of desertification and drought. *Down to Earth*, (14), pp.4–6.

Metcalf, G. & Jenkins, K., 2005. A Changing Climate for Business: Business Planning for the Impacts of Climate Change.

Metcalf, G. & Jenkinson, K., 2005. A Changing Climate For Business: Business Planning for the Impacts of Climate Change. *U.K. Climate Impact Program (UKCIP)*.

Meyer, A.D., Gaba, V. & Colwell, K.A., 2005. Organizing Far from Equilibrium: Nonlinear Change in Organizational Fields. *Organization Science*, 16, pp.456–473.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*,

Miller, K.A., Rhodes, S.L. & Macdonnell, L.J., 1997. Water allocation in a changing climate: institutions and adaptation. *Climatic Change*, 35, pp.157–177.

Mills, E. et al., 2006. From Risk to Opportunity: How Insurers Can Proactively and Profitably Manage Climate Change. *Office*, p.52.

Min, H. & Zhou, G., 2002. Supply chain modeling: past, present and future. *Computers & Industrial Engineering*, 43(1-2), pp.231–249. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360835202000669.

Mintzberg, H., Ahlstrand, B. & Lampel, J., 1998. *Strategy Safari*,

Mollica, R.F. et al., 2004. Mental health in complex emergencies. *Lance*, 364, pp.2058–67.

Moody, D., 2002. Empirical research methods. , pp.1–4.

Muld, A. & Toll, M., 2005. *Stormen Gudrun - Konsekvenser för nätbolag och samhälle*,

Munich Re, 2011. *NatCatSERVICE Natural catastrophe know-how for Risk Management Research*, Available at: http://www.munichre.com/publications/302-06733_en.pdf.

Obrien, K. et al., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change Part A*, 14, pp.303–313.

Ocampo, J. & Martin, J., 2003. Globalization and development: a Latin American and Caribbean perspective. *UN Eco Com Latin America*.

Okazumi, T. et al., 2012. Lessons Learnt from Two Unprecedented Disasters in 2011: Great East Japan Earthquake and Tsunami in Japan and Chao Phraya River flood in Thailand. *Background Paper prepared for the 2013 Global Assessment Report on Disaster Risk Reduction.*

Oke, A. & Gopalakrishnan, M., 2009. Managing disruptions in supply chains: A case study of a retail supply chain. *International Journal of Production Economics*, 118(1), pp.168–174. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925527308002612 [Accessed August 9, 2013].

Oliver, K. & Webber, M.., 1982. Supply-chain management: logistics catches up with strategy. *Logistics*, (Outlook, Booz, Allen and Hamilton Inc.), pp.63–65.

Parry, M.L. et al., 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*, Cambridge University Press, Cambridge, UK, 976pp.

Peppard, J. & Rylander, A., 2006. From Value Chain to Value Network: *European Management Journal*, 24(2-3), pp.128–141. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0263237306000156 [Accessed August 9, 2013].

Plume, K., 2012. UPDATE 1-Cargill cuts barge draft due to low Mississippi River - Chicago Tribune. *Chicago Tribune*. Available at: http://articles.chicagotribune.com/2012-11-30/news/sns-rt-cargill-bargesrestrictions-update-1l1e8mu8k5-20121130_1_ingram-barge-mississippi-river-low-water [Accessed August 23, 2013].

Porter, M.E., 1985. *Competitive Advantage: Creating and Sustaining Superior Performance*,

Preble, J.F., 1997. Integrating the crisis management perspective into the strategic management process. *Journal of Management Studies*, 34, pp.769–791.

Reynolds, C., Crompton, L. & Mills, J., 2010. Livestock and climate change impacts in the developing world. *Outlook on Agriculture*, 39, pp.245–248.

Rosenzweig, C. et al., 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In M. . Parry et al., eds. Cambridge: Cambridge University Press, pp. 79–131.

Rumsby, B.T. & Macklin, M.G., 1994. Channel and Floodplain Response to Recent Abrupt Climate-Change - the Tyne Basin, Northern England. *Earth Surface Processes and Landforms*, 19, pp.499–515.

Saito, Y., 2001. Deltas in Southeast and East Asia: their evolution and current problems. In *Proceedings of the APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in Asia - Pacific Region*. Kobe: Asia Pacific Network for Global Change Research, pp. 185–191.

Scheffer, M. et al., 2001. Catastrophic shifts in ecosystems. *Nature*, 413(6856), pp.591–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/11595939 [Accessed August 10, 2013].

Schneider, S. et al., 2007. *Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working*,

Selangor, U.I. & Alam, S., 2008. Case Study : A Strategic Research Methodology Khairul Baharein Mohd Noor. , 5(11), pp.1602–1604.

SMHI, 2012. Klimatanalyser. Available at: http://www.smhi.se/klimatdata/klimatscenarier/klimatanalyser/vattenforhallanden-1.22672 [Accessed August 20, 2013].

Solomon, S. et al., 2007. Technical Summary. Available at: http://ecite.utas.edu.au/50315/1/Solomon 2007.pdf [Accessed August 10, 2013].

Spekman, R.E. & Davis, E.W., 2004. Risky business: expanding the discussion on risk and the extended enterprise. *International Journal of Physical Distribution & Logistics Management*, 34, pp.414–433.

Srai, J.S. & Gregory, M., 2008. A supply network configuration perspective on international supply chain development. *International Journal of Operations & Production Management*, 28, pp.386–411.

Stephenson, D.B., 2008. weather and climate events.

Stern, N., 2007. STERN REVIEW : The Economics of Climate Change Introduction STERN REVIEW : The Economics of Climate Change. *STERN REVIEW The Economics of Climate Change*, 17, p.712.

Stevens, G.., 1989. Integrating the Supply Chain. *International Journal of Physical Distribution & Materials Management*, 19, pp.3–8.

Sussman, F.G. & Freed, R.J., 2008. No Title. In *Adapting to Climate Change: A Business Approach*. Pew Centre on Global Climate Change.

Svensson, G., 2000. A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution & Logistics Management*, 30, pp.731–750.

Tang, C.S., 2006. Perspectives in supply chain risk management. *International Journal of Production Economics*, 103(2), pp.451–488. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0925527306000405 [Accessed August 8, 2013].

Thomas, D.S.G. & Leason, H.C.C.A.C.D., 2005. Dunefield activity response to climate variability in the southwest Kalahari. *Geomorphology*, 64, pp.117–132 ST – Dunefield activity response to clima.

Thomson, E. & Woods, R., 2012. Copec Falls Most in Four Weeks as Chile Wildfires Destroy Plywood Factory - Bloomberg. *Bloomberg*. Available at: http://www.bloomberg.com/news/2012-01-02/copec-falls-most-in-five-weeks-as-chile-wildfires-destroy-plywood-factory.html [Accessed August 23, 2013].

Turner, B.L. et al., 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100, pp.8074–9.

UK Met Office, 2011. Climate: observations, projections and impacts. Available at: http://www.metoffice.gov.uk/climate-change/policy-relevant/obs-projections-impacts [Accessed August 28, 2013].

UKCIP, 2010. The UKCIP Adaptation Wizard V 3.0 UKCIP. Available at: www.ukcip.org.uk/cwizard.

UNISDR, 2013. *From Shared Risk to Shared Value : The Business Case for Disaster Risk Reduction*,

Webster, P.J. et al., 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, 309, pp.1844–6.

Wilbanks et al., 2007. *Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*,

Wilbanks, T.J. et al., 2007. Toward an integrated analysis of mitigation and adaptation: some preliminary findings. *Mitigation and Adaptation Strategies for Global Change*, 12, pp.713–725.

Wilby, R.L., 2007. A Review of Climate Change Impacts on the Built Environment. *Built Environment*, 33, pp.31–45.

WMO, 2009. Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation. , (72).

Yin, R., 1984. *Case study research: Design and methods* 1st ed., Beverly Hills, CA: Sage Publishing.

Yin, R.K., 2009. *Case Study Research: Design and Methods*,

Yin, R.K., 1994. *Case study research: design and methods, Applied Social Research Methods Series, vol. 5*,

Yohe, G. & Tol, R.S.J., 2002. Indicators for social and economic coping capacity - Moving toward a working definition of adaptive capacity. *Global Environmental Change*, 12, pp.25–40.

Appendix

1 Extreme Weather Typology

Extreme events	WMO	BAS	Munich Re	SMHI	EA	NUC	4CMR
Heavy precipitation	✓	✓	✓	✓	✓		✓
Heavy snow load	✓	✓		✓			
Heat waves	✓	✓	✓	✓	✓		✓
Cold spells	✓	✓	✓		✓		✓
Drought	✓		✓	✓	✓		
Wind storms	✓	✓	✓	✓	✓		✓
Floods	✓		✓	✓	✓		
Fog		✓					
Ice concentrations		✓					
Sea level rise (Storm surge)					✓		
Landslides (wet)			✓				

2 Extreme Weather Definitions

Definitions	WMO	BAS	Munich Re	SMHI	EA	NUC	4CMR
Rarity (i.e. long return period)		✓	✓	✓			
Catastrophic (low probability high impact)						✓	
Exceed fixed thresholds (Intensity/frequency /duration)	✓		✓	✓	✓		
Exceed thresholds using underlying statistical distributions	✓	✓		✓	✓	✓	✓
Potential of severe losses	✓	✓	✓		✓		
Distribution (space scale)	✓						
Chronic extremes						✓	

3 Challenges in data analysis

Challenges in analysis	WMO	BAS	Munich Re	SMHI	EA	NUC	4CMR
Lack of statistics on rare events		✓	✓	✓	✓		
Grid-data coverage and quality		✓					✓
Definition do not reflect impact severity of impact	✓	✓			✓	✓	
Definitions geographically dependent	✓				✓		
Correct use of reference period	✓						
Impact of climate change on reference period	✓				✓		
Limited understanding of sequence of extremes					✓		
Limited understanding of compound events					✓		
Impact of chronic non-extremes						✓	
Cost of impact have to be adjusted		✓					

4 Industrial functions at risk

Industrial functions at risk	WMO	BAS	Munich Re	SMHI	EA	NUC	4CMR
Design features				✓			
Distribution of water resources				✓			
Long term investment strategies	✓	✓					
Rain-fed agriculture	✓						
Commerce corridors	✓	✓			✓	✓	
Logistics and distribution	✓	✓					
Public services and lifelines	✓	✓				✓	
Tourism	✓						
Process environments			✓				✓
Wider socio-economic implications					✓		
Human health							✓
Market demand	✓						

5 Extreme weather database

Database	Area	Recommended by
Epidemiology Research Centre	Worldwide	WMO
IPCC SREX	Worldwide	WMO, BAS, SMHI, Munich Re, EA, NUC
DesInventar	Worldwide	NUC
Munch Re NatCatSERVICE	Worldwide	Munich Re
World Bank Data Portal	Worldwide	EA
UK Climate Projections	Regional	EA
UKCIP	National	EA
UK Met Office	Worldwide	BAS
SPC NOAA	National	Munich Re, EA
Prudence	Regional	4CMR
SMHI Metadata	National	SMHI
5C Centre	Regional	EA

Risk and resilience in global supply networks: how demand, design, and coordination affect financial and operational performance

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ABSTRACT

In this paper we extend our research on how variation in random demand patterns influences supply chain performance by investigating *structural demand* patterns, such as those common in the computer industry. Structural demand patterns pose additional challenges to managing supply chain inventories and costs, and the strategies that are optimal for managing random demand variation are not the same as those for managing structural demand patterns. In addition, optimal strategies for companies performing aggregate planning for structural demand are often different than those for suppliers. Buying companies may choose one optimal strategy, suppliers another, and yet that set of strategies is very likely to not be the globally optimal strategy.

Key words: demand variation, supply chain costs, optimization, computational model, capacity constraints

INTRODUCTION

Demand variation has been studied in many contexts in the past, including studies on coordination and collaboration to improve visibility of demand throughout the supply chain. But there has been little research on exactly how this coordination can generate optimal demand management strategies between buyers and suppliers under conditions of capacity constraints when the demand patterns have a structure that is not based on random deviations from a mean or trend line.

Structural demand occurs in industries such as the computer industry, where distinct weekly, monthly and quarterly patterns emerge and persist due to deeply ingrained buying patterns driven by influential customers. Influential customers have learned, for example, that waiting to buy until late in a quarter allows them more negotiating leverage since computer

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companies are eager to book orders prior to the end of a month or quarter to enable them to report higher sales at the end of regular reporting periods. These buying patterns create lumpy demand at the end of each month and even more lumpy demand at the end of each quarter, where more than thirty five percent of quarterly sales may be booked in the last week of the quarter.

Accommodating structural demand can be expensive. Attempting to level demand and reduce sales discounts at the end of the month or quarter, which is common in retail merchandizing to better utilize supply chain capacity and lower production costs, can backfire on computer original equipment manufacturers ("OEMs"). The margins on high volume servers, for example, are much higher than retail merchandizing, so OEMs that attempt to level demand and reduce sales incentives may quickly lose sales to competitors who continue to allow the discounts as a normal part of the sales cycle. Where order quantities for a given request for proposal may be for a thousand servers that sell for several thousand dollars each, buyers have considerable purchasing leverage and competition is significant even when a smaller number of OEMs participate in the market. In addition, buyers also have the luxury of deferring sales for a period of time to improve their negotiating position, so OEMs are reluctant to unilaterally impose demand smoothing practices on large business and governmental customers. To provide a perspective on the scale of the problem, revenue for high volume server product lines can approach or exceed a billion dollars per year. Small changes in percentage of profitability can result in profit changes of millions or tens of millions of dollars.

In this study we investigate the effects of structural demand on firm performance by comparing profitability of optimal aggregate planning strategies for structural demand and random demand. We start by studying cases of demand that have random variation from a mean value and then examine cases of structural demand that have the same levels of random variation. We initially investigate cases of zero variation, then increase the levels of variation though our experimental design. Three types of aggregate production plans are included in the experimental design, including random aggregate plans for producing to a mean demand level, as well as front loaded and back loaded aggregate plans for accommodating structural demand requirements. To represent realistic scenarios we add two levels of safety stock.

To evaluate firm performance, we evaluate profitability for optimal solutions for T0, for T1 and for the supply chain consisting of the combined profitability of T0 and T1. We seek to answer the research question: *"what is the optimal strategy for maximizing supply chain profitability for firms that experience structural demand?"*

This study extends our prior work to continue building a foundation of the building blocks of supply chain design. Recently we investigated the effects of low and high demand variation on supply chain costs and identified the challenge of managing nonlinear relationships due to interactions between the underlying costs (Burns and Tseng, 2012), the development of a "next generation" end to end supply chain performance measurement and prediction system (Burns, Tseng and Berkowitz, 2010), and the relationship between different archetypes of value chain design and resilience (Burns and Melnyk, 2009). In addition, near the end of the paper we preview preliminary results on developing a more comprehensive framework for understanding supply chain risk from a study funded by NASA.

BACKGROUND

From prior literature we identified that firms analyze patterns of demand and use this information to influence supply chain design to remain competitive (Fisher, 1997). Fine (1998) argued that the archetype of the supply chain, whether modular or integrated, affects how the supply chain performs and that firms choose one archetype or the other due to the benefits accruing a firm from employing a particular archetype.

Most of the prior research has been on more traditional demand patterns – based on random variations around a mean demand value or accommodating seasonality for forecasting demand. However, there is very little research on structural demand patterns. Firms in some industries may experience one or two seasonal periods in demand, yet demand in the industrial and governmental segments for servers produced in the computer industry is comprised of weekly, monthly and quarterly cycles that persist in their demand patterns. We define structural demand (SD) as periodic and persistent demand changes that occur with regularity within a given year. Thus while seasonal demand is a simple example of structural demand, the computer industry is a more interesting and challenging case.

In addition, variations in demand are often managed with safety stocks to ensure reduction in stock outs to customers. Safety stock are expensive to maintain but are important to aid in decreasing stock outs to enhance customer service and profitability. The retail value of assembled items and computer components in the computer industry decreases quickly over time, thus the recurring costs and increased rate of obsolescence push managers to keep safety stocks to a minimum.

From a customer perspective, a common optimal strategy is to receive components just prior to the production date. From a supplier perspective, a common optimal strategy is to produce and ship as early as possible to maximize earlier cash flow and allow later available capacity to support additional orders. From a supply chain perspective, collaboration is necessary to find a globally optimal solution to help reduce costs to end customers. In the next section we discuss the methods employed in this study to accommodate these challenges and answer the research question.

METHODOLOGY

We use a mixed integer linear programming model (MILP) to determine optimal solutions for T0, for T1, and for the overall supply chain under conditions of deterministic demand. We then use the validated computational model to evaluate firm performance when incorporating weekly variation in demand. Using the computational model, we run a statistically significant number of runs per scenario from the experimental design to evaluate differences in firm performance across each of the cells of the experimental design.

We can show that in cases of zero demand variation (known, or deterministic, demand) there exists an optimal supply chain solution, and we can provide a method to identify the value of the optimal solution to an OEM. But when random variations affect demand based on a mean (Figure 1) or on a structural demand pattern (Figure 2), safety stock is needed to buffer the demand variation. Firms can choose to employ different aggregate planning approaches which in turn yield differing results.

Figure 1 - Random demand pattern (annual) centered around a mean value

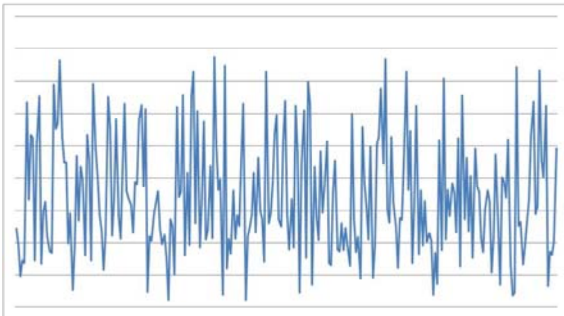
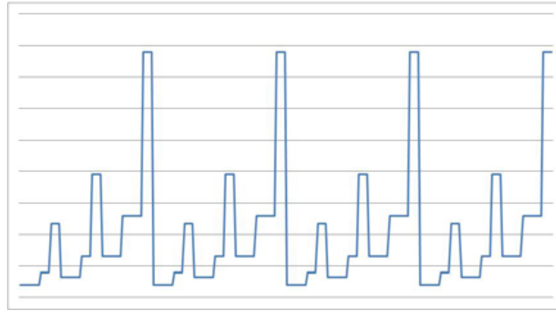


Figure 2 - Structural demand pattern (annual) common in some computer industry segments



We start with an MILP model to determine optimal T0 and T1 aggregate planning strategies under known demand conditions. Once random variation enters the picture, the assumptions of the MILP model, such as known demand, are no longer valid. To accommodate random deviations in known demand patterns, we start with the optimal aggregate planning schedules from the MILP model and use these as inputs to the computational model to add or subtract random deviations from the optimal solutions. Computational models are a more appropriate method to investigate how random variation affects firm performance.

After discussing the deterministic demand case as a baseline that was determined from the MILP model, we proceed to outline the elements of the experimental design for the computational model, including demand patterns, weekly demand variation, aggregate production planning, and safety stock.

Deterministic demand

We begin by employing an MILP model to determine optimal solutions for aggregate production planning using known, or deterministic, demand from an OEM at Tier 0 (T0) in the supply chain and for an immediate supplier of a key component at Tier 1 (T1) for the OEM. In the case of deterministic demand, we derived a mathematical proof demonstrating that while there are multiple optimal solutions for aggregate planning for T0 and for T1, there exists at least one global solution that optimizes costs for both T0 and T1.

The lower complexity case of deterministic demand lends insight into how to develop contract incentives to coordinate aggregate planning across the supply chain and aid in determining what the value is to the firms when achieving the optimal solution. This insight places an upper limit on the value of incentives offered to T1 to improve coordination by identifying the specific cost savings available to T0.

Demand pattern

In the more realistic case of random demand variation, either varying about a mean value or varying week by week in the case of structural demand patterns, we can also glean insights into how to combine the insights of an optimal solution with managing localized weekly demand variation through the use of minimal safety stocks. As noted, to accommodate this inquiry we employ a computational model that calculates the mean or structural demand value by week and adds random variation in demand to each week according to the experimental design.

Weekly demand variation

Examining the effects of weekly demand variation, as measured by coefficient of variation (c.v.), allows investigation of how sensitive firm profitability is to increasing weekly demand variation. Zero weekly demand variation is the deterministic case. In addition to the zero variation case, we examine weekly demand variation at c.v. = 0.05, 0.10, and 0.15 (five, ten and fifteen percent) levels.

Aggregate production planning

Three aggregate production plans are investigated: *random*, *front load*, and *back load*. If capacity was not limited, T0 would simply request that T1 pursue a pure chase strategy, producing small or large quantities just as they are needed. But tooling and lead times in the computer industry are significant, and capacity is expensive, so suppliers do not invest in significant excess capacity.

The optimal aggregate production plan for demand planning for *random* demand is to plan to the mean demand for each period and use safety stock to accommodate weekly variation. *Front loaded* production plans are optimal for a Tier 1 supplier that can ship early, maximizing early cash flow and allowing later available capacity to be available for additional orders that may arise. This is one of the optimal solutions for T1 when T0 pays for shipping and storage of finished goods, but it clearly is not optimal to T0 for cost reasons due to inventory arriving earlier than required for T0 production.

Back loaded production plans are equivalent to a chase strategy, where T1 produces immediately prior to T0 requiring the product. Under deterministic demand, back loaded is the optimal solution for T0. Incorporating demand variation requires the use of safety stock inventory to accommodate the variation. This creates a trade-off from the T0 perspective: firms can schedule deliveries from T1 at the last minute and require T1 to carry safety stock, which in the end is priced into the product for T0, or build a little early at T1 and reserve some later capacity while holding lower safety stock inventories at T1. Under demand variation, back load is one of the optimal solutions that is most advantageous to T0 but it presents a risk to T1 (and T0) should machine failures or transportation difficulties arise, since it increases the risk of non-delivery due to temporary disruptions or to a weekly increase in demand beyond what the safety stocks can support.

In this study, gross margin is defined as revenue minus sourced component cost. For this study, the price for the T1 critical component (e.g. a processor chip or system board) comprises 33% of the total sourced component cost for T0, which is equivalent to 15% of T0 revenue per unit. The T1 aggregate production plans used in this study correspond to T0 optimal, T1 optimal, and random variation optimal aggregate plans as shown in Table 1.

Table 1 - T1 Aggregate Production Plans – for each quarter

	T0 Opt T1 AggPln Backload	T1 Opt T1 AggPln FrontLoad	 T1 AggPln Random
Week 1	1,950	11,000	10,000
Week 2	7,050	11,000	10,000
Week 3	11,000	11,000	10,000
Week 4	11,000	11,000	10,000
Week 5	11,000	11,000	10,000
Week 6	11,000	11,000	10,000
Week 7	11,000	11,000	10,000
Week 8	11,000	11,000	10,000
Week 9	11,000	11,000	10,000
Week 10	11,000	11,000	10,000
Week 11	11,000	11,000	10,000
Week 12	11,000	9,000	10,000
Week 13	11,000	0	10,000

Safety stock

Safety stock in the computer industry is viewed similarly to a perishable item, not because it degrades in quality but because each week that a component sits in inventory its value decreases due to the high pace of obsolescence of computer components. Due to the high cost and obsolescence risks, managers work diligently to keep safety stocks to a minimum.

Experimental design

We execute a 48-factoral design, comprised of two demand patterns, four levels of weekly variation, three types of T1 aggregate production plans, and two levels of safety stock (Table 2). As noted the two types of demand patterns are random and structural. We use four levels of weekly variation from the normal average demand for a given week (whether random or structural): 0%, 5%, 10%, and 15%. The aggregate production schedules employed for T1 include random demand, a front loaded schedule, and a back loaded schedule. The safety stock levels include five days and ten days of safety stock. We set capacity at 110% of average demand, since the research client contracts for 10% reserve capacity per quarter. Since capacity for electronic circuits and technologies are very expensive, underutilized capacity is quickly sold or bid away in the high clockspeed environment of computer technologies.

Table 2 - Experimental design factors

Demand pattern	Weekly demand variation	T1 Aggregate production plan	Safety stock
random	0% 5% 10% 15%	produce to quarterly mean	5 days 10 days
structural	0% 5% 10% 15%	front load (FL)*	5 days 10 days
		back load (BL) *	5 days 10 days

Parameters (actual data disguised due to confidentiality): annual demand = 520,000 units; capacity = 110% of mean quarterly demand; T0 gross profit percent = 70%, back orders allowed

* These are two of the optimal T1 aggregate production plan strategies, one if which is also globally optimal for the supply chain as determined by subsequent analysis. The other T1 optimal strategies are mixed strategies, none of which is globally optimal.

The results of this study shown in the next section are presented in the form of profitability levels of T0, T1 and global supply chain profitability. For T1, the for choice of aggregate plan results in changes to inventory carrying costs but not for T0, since for T0 demand is met on time by T1 via each of the available optimal schedules for T1. For T0 optimal strategies, T1 meets the demand on time but the time that T1 ships may vary depending on the choice of aggregate plan by T1. For the globally optimal supply chain strategy, an optimal solution must be optimal for T0 and T1 and must also be globally optimal. Most of the potential optimal solutions for T0 and T1 are not jointly optimal for the supply chain.

When the differences in inventory carrying costs are placed in the context of overall profitability for T0 and T1, the changes are small relative to the revenue to T0 from the assembled unit, but represent a larger portion of the cost incurred by T1. Similarly the differences in inventory carrying cost for T0 are small relative to the selling price of servers to end customers. But for a market where a given product line of T0 may comprise more than a billion dollars in sales, a one percent change translates to a change of ten million dollars or more for input costs from T1, and a one-tenth percent change at T0 is greater than a million dollars. Correspondingly, these million-dollar-plus per product line improvements across a range of products sourced from a given critical supplier constitute significant savings from which to devise contractual incentives to capture these potential savings from critical suppliers.

DISCUSSION

This study focuses on one key component from a Tier 1 supplier to a Tier 0 OEM. The results demonstrate that for even one component of one product line there can be savings of millions of dollars. A discussion of the demand patterns and the no-variation versus variation cases follows.

No demand variation case

In an optimal case of just in time production with known demand, with no demand variation, and with just in time delivery there would be no safety stock required. T0 would earn 70% gross profit using the parameters set in this example, and the maximum global supply chain profits in this example would be 81.5%. While this "perfect case" does not exist in reality, it does provide an upper bound for what is achievable under the more realistic cases of demand variation.

Demand variation case

Results for T0 and T1 with demand variation are shown in Figure 3 as a percent of unit profitability for T0 and T1 sales price, respectively. Results for supply chain (SC) profitability in Figure 3 include the sum of T0 and T1 profitability by unit and are shown as a percent of T0 sell price. Figure 3 shows results from the computational model where Front Loaded (FL), Back Loaded (BL) and Random (RAN) demand variation aggregate plans were used. We tested demand variation using coefficients of variation ("c.v.") = 0%, 5%, 10% and 15%. The results for the varying levels of c.v. were similar across these lower levels of random demand variation, which was not the case in our prior study that evaluated higher levels of demand variation based on random demand patterns (Burns *et al.*, 2012).

Figure 3 - Results for T0, T1 and supply chain profitability

	Avg T0 unit profit%	Avg T1 unit profit%	Avg SC unit profit%
Random demand overall	**69.64%**	**68.72%**	**79.95%**
Random w/ 5 days SS	69.81%	69.10%	80.18%
Random w/ 10 days SS	69.47%	68.35%	79.72%
Front Load (FL) overall	**69.41%**	**66.11%**	**79.33%**
FL w/ 5 days SS	69.30%	66.11%	79.22%
FL w/ 10 days SS	69.52%	66.11%	79.43%
Back Load (BL) overall	**69.41%**	**66.24%**	**79.35%**
BL w/ 5 days SS	69.30%	66.23%	79.24%
BL w/ 10 days SS	69.52%	66.24%	79.45%

Note: SS = safety stock

Random demand

For the random demand case, the lower levels of safety stock inventory are more profitable for T0, T1 and SC. This result was expected but provides a contrast from which to understand results for the structural demand case. This is a result of a pooling of the variation that cannot be effectively applied in the structural demand case. In the structural demand case, the peak demand week arises at the end of each quarter, and shortages resulting from insufficient safety stock are problematic for sustaining high customer service levels. While infrequent backorders are allowed, persistent backorders will cause customers to switch suppliers, which can be very costly to an OEM.

Structural demand – FL and BL

The FL strategy for T0 suggests that T0 is more profitable using 10 days of safety stock, and the FL strategy is equally profitable with the BL strategy. For T1 while using an FL strategy, either safety stock level is equally profitable, but the BL strategy for T1 is more profitable than the FL strategy, and the ten days of safety stock is more slightly more profitable for the T1 BL strategy. For global supply chain (SC) profitability, the five days of safety stock is less profitable than the ten days of safety stock.

Insights

This suggests that firms may improve profitability by reducing safety stock for demand that follows random variation about a mean value and by maintaining somewhat larger safety stocks for demand that follows a structural demand pattern. But the interesting question for a real company is when this switches; at some point there is a threshold by which the better strategy for a demand pattern with a lower degree of structure switches to being more profitable, and lower safety stock inventory is less profitable than employing higher safety stock inventory. Rather than firms having to individually compute this threshold to improve profitability in their supply chains, which is difficult at best, this insight helps identify a future area to extend this research.

Risks

For the global supply chain with structural demand, the BL strategy was slightly more profitable overall than the FL strategy, but again that strategy comes with the risk of no reserve capacity if demand peaks unexpectedly at the end of a quarter. For random demand, five days of safety stock strategy is slightly more profitable than the ten days of safety stock strategy, indicating that five days of safety stock inventory was sufficient and more profitable while handling the demand variation. If backorders are not allowed, the cost of stockouts can significantly affect the optimal strategies and change the profit structure. This is an additional area of future research.

CONCLUSION

The goal of this study is to provide insights into how to improve supply chain performance when firms experience structural demand patterns. Structural demands induce additional capacity utilization and cost challenges to firms while they work to balance the cost of capacity against the structure embedded in some demand patterns. One insight from the study is that the choice of aggregate planning method by suppliers can affect focal firm and supply chain performance, providing opportunities to value financial waste in the supply chain by using contractual mechanisms to incentivize suppliers to reduce global supply chain costs. Another is that the structural demand case with variation is more difficult to manage due to the challenges of capacity limits and the choices available for aggregate planning strategies.

We observed in the MILP model results that in the random demand variation case the optimal strategy for T0 and T1 is to produce to the mean demand per period and carry safety stock. This optimal strategy is not necessarily true for the structural demand case, where there are multiple optimal strategies available to T0 and T1 for structural demand variation.

For T1, the choice of optimal strategy matters. While an FL strategy provides more flexibility in having available capacity near the end of the quarter, it is a higher cost strategy due to the inventory carrying costs. The BL strategy is more profitable in general, but provides no reserve capacity from which to handle upswings in demand.

Yet only one of these combined strategies is optimal for the global supply chain, and it is not obvious without analysis what the optimal strategy is unless the firms collaborate on inventory costs and generate the appropriate analysis. As noted, the presence of shortage penalties would complicate this situation considerably, and is an area for future research.

Why does this matter to the OEM?

While the aggregate profit effects are small relative to T0 overall revenue for the server product line in this study, these results identify millions of dollars of potential savings from one product line that T0 can extract from the supply chain by reducing waste in its aggregate planning process in coordination with T1, and the millions of dollars of savings are much larger as a percentage of T1 revenue. This provides an important opportunity for T0 to improve SC governance and profitability by devising contract incentives to share some of this potential profit improvement with T1 as a contractual incentive to reduce excess inventory costs.

As a starting point, the lower complexity case of deterministic demand lends insight into how to develop contract incentives to coordinate aggregate planning across the supply chain and what the value to the firm is from achieving the optimal solution. This insight places an upper limit on the value of incentives offered to T1 to improve coordination by identifying the specific cost savings available to T0. And these are using optimal T1 and T0 strategies, which are not currently being used by the OEM, thus in practice the real savings are higher than presented here.

More importantly, this study focuses only on one key component for one tier one supplier. If this approach is implemented across the OEM supply chain, the potential profit improvement is an order of magnitude higher.

Future research

There are several opportunities for future research to extend this work. Understanding cases of demand variation between the extremes of random demand varying about a mean and the magnitude of structural demand variation in this study would shed insight into when the differing choices of optimal aggregate planning strategies for T0 and T1 cause a switch in the globally optimum supply chain strategy. Understanding how stockout costs affect the choice of aggregate planning strategies is also important, since for many products backorders are not a viable market option.

This study is part of a stream of research by the authors. This research stream includes other active studies in supply chain management, including a NASA-funded study on developing a more comprehensive supply chain risk framework that we will preview at the symposium.

REFERENCES

Burns, L. and Tseng, F. (2012), "The effects of demand patterns on supply chain costs for suppliers and manufacturers under supply chain constraints", The Annual Cambridge International Manufacturing Symposium, Cambridge, UK.

Burns, L., Tseng, F. and Berkowitz, D. (2010), "Global network analysis in a military supply chain: Using a systems-based approach to develop a next-generation end-to-end supply chain performance measurement and prediction system", The 15th annual Cambridge International Manufacturing Symposium, Cambridge, UK.

Burns, L. A. and Melnyk, S. A. (2009), "The relationship between value chain design and resilience: A framework of value chain design", 14th Cambridge International Manufacturing Symposium, Cambridge, England.

Fine, C. H. (1998), Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus Publishing, Perseus, NY.

Fisher, M. L. (1997), "What is the right supply chain for your product?", Harvard Business Review, Vol 75 No 2, pp. 105-126.

A 360 Degree View on Supply Chain Risk Identification

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Abstract
Identification of risk is a key concern for supply chains because of globalization and increasing complexity of supply chain networks. Highly interlinked networks imply that risk can occur from numerous sources. Hence, it is necessary to develop a comprehensive understanding of risk to identify and manage it effectively. Consequently, this paper aims to contribute to the knowledge about supply chain risk by presenting a 360 degree view on supply chain risk identification. Therefore, an extensive review of literature is carried out to recognize challenges of identifying supply chain risk and to find gaps in identification methodologies. Based on the findings, first, a conceptual view of risk and uncertainty is presented and distinction between supply chain and operational risk is drawn. Second, application of scenario planning is illustrated for identifying supply chain risks. Finally, a conceptual framework is presented to reconcile among proactive risk management, reactive risk management and resilience.

Keywords: Risk Identification, Supply Chain Risk, Review

Introduction:
Over the years, the fire incident at the Philips microchip plant in Albuquerque, New Mexico, in 2000 that simultaneously affected both Nokia and Ericsson, has appeared in the extant literature of supply chain risk management (SCRM) in different forms. While some researchers problematize this case as the inherent capability difference between Nokia and Ericsson (Sheffi & Rice, 2005; Mukherjee 2008), others cite this case as an argument for proactively managing risks (Chopra & Sodhi, 2004; Norrman & Jansson, 2004). Ironically, this case in literature has rarely been problematized as being an example of identification error. To emphasize this point further, a part of the case extracted from the very first article (Latour 2001) written about this case is presented here: "Within days, Nokia officials in Finland already had their first inkling that something was amiss. Order numbers weren't adding up, company officials say. On Monday, March 20, Tapio Markki, Nokia's chief component-purchasing manager, found out why. In a

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phone call to his office at Nokia headquarters in the city of Espoo, a Philips account representative informed him of the fire, saying the company had lost "some wafers" but the plant would be back to normal in a week, according to Mr. Markki. Philips officials say they were passing along the best information they had at the time, as quickly as possible. Within hours of getting the bad news, Messrs. Korhonen and Markki assembled their team of supply engineers, chip designers and top managers in China, Finland and the U.S. to attack the problem.
Meanwhile, across the Gulf of Bothnia in Stockholm, top Ericsson officials still hadn't realized what they were up against. Like Nokia, Ericsson officials first heard of the fire three days after it occurred. But that communication was "one technician talking to another," according to Roland Klein, head of investor relations for the company. "There were a few bits and pieces, but nothing formal." "The fire was not perceived as a major catastrophe," says Pia Gideon, a spokeswoman for the company."

Two big cell phone giants, same incident but different reactions; Nokia identified the risk and reacted quickly; Ericsson failed to identify the risk, hence, took no step. Result: Ericsson reported a loss of 2.34 billion dollars in the cellular phone division (Latour 2001) and ceased making cellular phones under its individual brand (Chopra & Sodhi 2004). The above case exemplifies how failure to identify risk can cost billions and eventually may result in loss of business. It also emphasizes importance of identifying risks before it gets "too late to recover". Hence, no wonder that risk identification is considered as a critical step for managing supply chain risk (Wu et al., 2006; Neiger et al., 2009; Rao & Goldsby, 2009; Kern et al., 2012). Despite immense importance of risk identification, several researchers noted lack of research in supply chain risk identification (Neiger et al. , 2009; Sodhi et al., 2012; Bandaly et al., 2012; Kayis & Karningsih, 2012). Hence, the primary purpose of this paper is to address this gap by developing a comprehensive understanding on supply chain risk identification. Accordingly, research questions of this paper are:

RQ1: What makes identification of risks difficult in supply chains?
RQ2: What are the existing tools/methods/frameworks for identifying supply chain risks?
RQ3: What are the current debates related to supply chain risk identification?

However, the contributions of this paper not only come from answering the above questions, but also come from the frameworks developed based on the findings. It is anticipated that these frameworks will provide an in-depth understanding of supply chain risk and its identification in theory and practice.

Method for Literature Search:
To develop a thorough understanding on risk identification, a secondary analysis of published peer-reviewed articles and grey literatures was undertaken. The reason for including grey literatures is that it contains recent problems, concerns and thoughts of industry people. Because supply chain risk management is an applied field of research it also makes sense to build understanding based on practitioners' cases. The search for published peer reviewed articles is performed on Web of Knowledge, Compendex and INSPEC. The references of the resultant articles from initial searches are explored again to find more articles on risk identification. The search for grey literature was mainly done using Google's advance search mechanism. After going through hundreds of articles only 72 articles including book sections, newspaper articles, whitepapers, and standards are kept for further analysis. These articles were read and analysed

extensively to search answers for the above research questions and to develop the corresponding frameworks.

Analysis and Findings:

In this section, findings from the analysis are presented in line with the research questions.

RQ1: Researchers and practitioners stated several issues that make supply chain risk identification difficult. One category of these issues relates to understanding of supply chain risks. The other category relates to inherent characteristics of supply chains. In the first category, two factors are found to be problematic. Firstly, the interchangeable use of risk and uncertainty in the prevalent literature of SCRM. As a result, confusion arises in theory and practice in comprehending whether supply chains should deal with uncertainty or risks. Attempts have been made by economics researchers to distinguish these seemingly inseparable concepts (Knight 1921). The main distinction drawn is that risk has known probability distribution and uncertainty has unknown probability distribution (Klimov & Merkuryev, 2008; Sodhi & Tang, 2012). However, such distinction is problematic especially for supply chain risk because probability distribution is often unavailable in practice (Manuj & Mentzer, 2008; Tang & Musa, 2011; Aven, 2012). Hence, a gap in research can be noted as lack of widely acceptable distinction between risk and uncertainty within supply chain context. Secondly, in SCRM literature, operational risks are categorized under supply chain risks (Basu et al., 2008; Manuj & Mentzer, 2008; Knemeyer et al., 2009; Sodhi et al., 2012); whereas in Operational Risk Management (ORM) literature, supply chain risk is categorized under operational risks (Adhitya et al., 2009, Silvestri et al. 2009). Such categorization is also problematic because these risks are fundamentally different; therefore, require different tools, techniques, capabilities and resources to manage. The evidence of these two risks being different and hence, require different techniques to manage is highlighted in the existing literature as “the success in choosing the mitigation strategies will depend a lot on understanding the difference between Supply Chain and Operational Risks” (Deloitte Insights 2013, VanderBok et al. 2007) and “companies are essentially fighting new war with old strategies”(Mitroff & Alpaslan, 2003). However, an effort to create distinctions between these two risks is still missing in the existing literature of SCRM.

In the second category, practitioners and researchers mentioned several inherent factors of supply chains that make identification of risks difficult. These factors are listed in Table 1. From Table 1, it is evident that supply chain identification cannot be successful, if, carried out in isolation inside the boundary of an organization. It requires significant collaboration from other supply chain members.

Table 1: Factor that makes risk identification difficult

Factors	**Explanation**	**Reference**
Visibility	Companies only claim to have visibilities up to second tier suppliers. Often risks arising at suppliers' premises are impossible to detect.	Deloitte Survey (2013); Kersten et al. (2011); VanderBok et al. (2007)
Complexity	It is often hard to detect interconnectedness and interdependency of supply chain risk due to the complexity in supply chain networks.	Manikandan et al., (2011) Canbolat et al., (2008);
Globalization	Customers and suppliers are part of different	Deloitte Insights

Factors	Explanation	Reference
	economic and societal environments which increases the potential sources of risk making it even more difficult to identify.	(2013)
Collaboration	Detection of risk requires a high degree of collaboration among supply chain partners which may not exists due to technological differences or lack of trust.	Deloitte Survey (2013)
Monitoring	The ability to monitor supply chain events and patterns as they happen is not always possible. Deloitte's press release (2012) reveals that 75% of global executives admit having no monitoring mechanism.	Deloitte Press Release, (2012); Vilko, (2012)

RQ2: Researchers have adopted different methodologies for identification of supply chain risk. These methodologies can be divided into four categories: simple listing/checklist, taxonomy based approach, scenario planning and process mapping (Singhal et al. 2011). In listing method, brainstorming exercises are carried out in order to generate a comprehensive list of known risks (Adhitya et al., 2009; Singhal et al. 2011). Taxonomy based approaches provide structured frameworks to elicit and organize risk identification activities related to various business functions. Classifying risk according to material, information and economic flows are examples of taxonomy based risk identification (Singhal et al., 2011; Cagliano et al., 2012). In a scenerio planning appraoch, risk profiles are developed by pinpointing fundamental risk factors and developing scenrios based on their effects on supply chain performance (Singhal et al., 2011). The process mapping method is performed by mapping key processes of supply chain operations and then recognizing risks that affect these processes. A comparison among these methods is illustrated in Table 2 to provide further insights on these methods. To compare these methods their ability to capture different componenets/attributes/dimentions of risks are analyzed. The components of risk as explained in the AS/NZS 4360:2004 are as follows:

"A risk is associated with:
(a) A source of risk – the thing which has the intrinsic potential to harm e.g. competitors, government etc.
(b) An event or incident – something that occurs such that the source of risk has the impact concerned e.g. competitors expand into or leave the market area, new or revised regulations etc.
(c) A consequence, outcome or impact on a range of stakeholders and assets e.g. environmental damage, loss or increase of markets/profits, regulations etc.
(d) A cause (what and why: usually a string of direct and underlying causes) for the presence of the event e.g. design, human interventions, predictions or failure to predict competitors' activity etc.
(e) Controls and their level of effectiveness e.g. detection systems, policies, security, training, market research and surveillance of market.
(f) When (frequency or time) where (location) could the risks occur."
In order to make the list of components complete another attribute "Target" proposed by Silvestri et al., (2009) is added to the above list. Target as described by Silvestri et al., (2009) are people, process, equipment and environment that need to be safe guarded from the risk sources.

Other than the above risk attributes, several researchers noted other attributes of these methods that are relevant to draw a comparison. For instances, flexibility of using a method (Adhitya et al., 2009), ability of a method to diagnose the interconnectedness among various risks events (Adhitya et al., 2009; White, 1995) and ability of a method to predict risk before it occurs (White 1995, Dani & Ranganathan 2008) are few examples of other dimensions considered by researchers. The comparisons among different risk identification methods based on the aforementioned dimensions are depicted in Table 2.

Table 2: Different Risk Identification Methods in Supply Chain

	Attributes	**Listing**	**Taxonomy**	**Scenario Planning**	**Process Mapping**			**Reference**
					FMEA/ FMECA	HAZOP	Others	
Usability Dimensions	Flexibility	X	X					Adhitya et al. 2009
	Complexity Handling			X		X		Adhitya et al. 2009, White 1995
	Predictability of Risk			X				White 1995, Dani & Ranganathan 2008
Risk Dimensions	Source	X	X	X	X	X	X	Adhitya et al. 2009, White 1995
	Cause (Where and what)			X	X	X	X	Adhitya et al. 2009, White 1995
	Consequence			X	X	X	X	Adhitya et al. 2009
	Risk Event	X	X	X	X	X	X	Adhitya et al. 2009
	When (Time)			X				Adhitya et al. 2009
	Where (Location)			X	X	X	X	Chopra and Sodhi 2004
	What (Target)			X				Silvestri et al., 2009

Table 2 highlights that listing and taxonomy based methods are very flexible to use but can not handle complexitiy or interconnectedness among supply chain risks nor can these methods recognize cause and effect of risks (Adhitya et al., 2009). On the other hand, process mapping performs fairly well in recognizing most dimensions, however, it still falls short in predicting risk or capturing time and target dimensions of risks (White, 1995). From the table, scenrio planning seems to be the most promising of all the approaches. This finding matches a similar finding by Singhal et al., (2011) that claims scenario planning method is the most accepted method in the literature.

Table 3 illustrates the extent of applications of these methods by researchers and allows several conclutions to be drawn. Fifty percent of the researchers used taxonomy and listing based methods while other fifty percent used different types of process mapping appraoches to identify supply chain risks. Among process mapping appraoches, FMEA is the most proposed method for identifying supply chain risks. Scenerio planning is the least proposed method among all which is surprising considering its abilities to capture different dimentions of supply chain risk.

Table 3: Methods for Identifying Supply Chain Risks

Sl	**Authors**	**Year**	**Method for identifying risk**					
			Listing	Taxonomy	Scenario Planning	Process Mapping		
						FMEA/ FMECA	HAZOP	Others
1	Hallikas et al.	2002		1				
2	Christopher et al.	2003	1					
3	Harland et al.	2003	1					
4	Mitroff & Murat	2003		1				
5	Chopra & Sodhi	2004	1					
6	Norrman & Jansson	2004						1
7	Svensson	2004		1				
8	Sinha et al.	2004				1		
9	Kleindorfer & Saad	2005		1				
10	Cucchiella & Gastaldi	2006	1					
11	Wu et al.	2006	1					
12	Bogataj & Bogataj	2007	1					
13	Canbolat et al.	2007				1		
14	Faisal et al.	2007		1				
15	Li & Hong	2007						1
16	Blackhurst et al.	2008	1					
17	Dani & Ranganathan	2008			1			
18	Pavlou & Manthou	2008	1					
19	Adhitya et al.	2009					1	
20	Neiger et al.	2009						1
21	Oehmen et al.	2009						1
22	Tuncel & Alpan	2010				1		
23	Kersten et al.	2011	1					
24	Lin & Zhou	2011						1
25	Manikandan et al.	2011	1					
26	Tummala & Schoenherr	2011				1		
27	Cagliano et al.	2012						1

Sl	Authors	Year	Method for identifying risk					
			Listing	Taxonomy	Scenario Planning	Process Mapping		
						FMEA/ FMECA	HAZOP	Others
28	Griffis & Whipple, 2012	2012				1		
29	Kayis & Karningsih	2012						1
30	Lee & Hong	2012				1		
31	Lockamy & McCormack	2012		1				
32	Vilko et al.	2012				1		
		Total	10	6	1	7	1	7

RQ3: Table 4 depicts key debates related to supply chain risk identification in present day SCRM literature. The disputes are basically among three concepts: managing risks either proactively or reactively or by building resilience. Theoretically, there should not be any debate among these concepts because these are various ways of managing risks in supply chain. However, the presence of the debates highlighted in Table 4 suggests the need to reconcile among these concepts.

Table 4: Current Debates Relating to Risk Identification

SL	Points	Counter Points	References
1	Proactive identification of risks is important in order to manage them effectively.	Building resilience is important because it is impossible to identify all risks. Resilience will enable supply chains to react and recover from the disruptions quickly.	Sodhi & Tang, 2012; Vilkio 2012; Deloitte Debates 2013
2	Identifying and monitoring risks are important because the earlier the risks are visible, the more options there are to manage them.	It is impossible to plan for something which never occurred before. The important thing is to handle risk reactively i.e. when it materializes.	Deloitte Debates 2012; Mitroff & Alpaslan, (2003)
3.	Risks can strike quickly and without a trail and may not always give a chance to react; therefore, setting up monitoring mechanisms can help to detect the risks early.	Big risks give ample signals when they arrive. Therefore, detecting it as soon as it occurs and reacting to it quickly is key for supply chains.	Deloitte Debates, 2012; Dani & Ranganathan, (2008);

To summarize, the key findings from the above discussions are:

(a) There is a need to distinguish between concepts such as risk and uncertainty, supply chain risk and operational risk within supply chain context.
(b) There are some inherent factors of supply chain risk such as visibility, collaboration etc. that creates barriers for identification of supply chain risks.
(c) Identification methods except scenario planning approach are fairly limited in their abilities to capture the entire set of risk attributes for supply chain risks.

(d) A framework is required to reconcile among these concepts such as proactive risk management, reactive risk management and resilience.

Addressing the gaps:

Based on the aforementioned findings, following things are presented in this paper:

(a) A conceptual view of risk and uncertainty
(b) Operational risk versus supply chain risks
(c) Illustration of scenario planning as a method for capturing risk attributes
(d) A conceptual framework to reconcile proactive and reactive risk management and resilience

(a) A conceptual view of Risk and Uncertainty:

Historically, risk has been represented using two dimensional constructs: probability of occurrences of an event and severity of consequences from the event (Hallikas et al, 2002; Knemeyer et al., 2009; Thun & Hoenig, 2009). Consequently, risk is distinguished with uncertainty in terms of known and unknown probability distributions (Klimov & Merkuryev, 2008; Sodhi & Tang, 2012). Such distinction between risk and uncertainty are limiting for two reasons:

(1) Risk is not necessarily a two dimensional construct and as illustrated before, risk has multiple attributes
(2) Probability of distributions may not readily available in practice especially for supply chain risks

To overcome these limitations a conceptual view of risk and uncertainty is presented in Figure 1 using a known-unknown continuum of risk and consequence type.

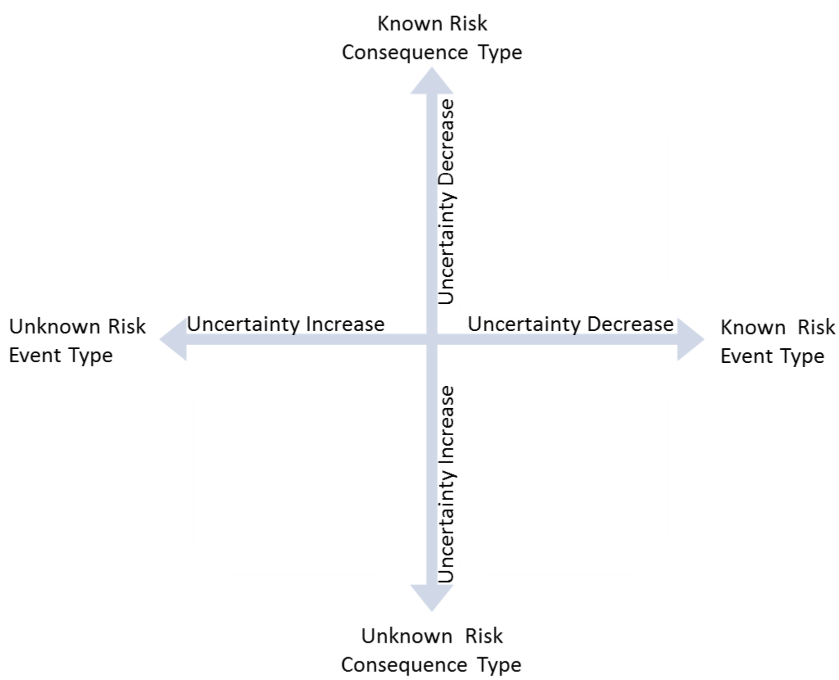

Figure 1: Conceptual View of Risk and Uncertainty

As knowledge increases the uncertainty of an event decreases, the extent of that reduction depends on how much is known about different attributes of risk such as source, event, consequence, when and where it can occur and what (target) it can affect. All this information/knowledge can be gathered if risk types or consequence types are known. However, the same is not possible for unknown risk or consequence types. For instance, before 9/11, hardly any researchers mentioned terrorism as a supply chain risk; after 9/11, terrorism is considered as one of the key risks for supply chains (Cohen & Kunreuther, 2007; Knemeyer et al. 2009; Cagliano et al. 2012). Similarly, types of consequence from supply chain risk such as the "political risk" can be unknown until the risk occurred and the consequence experienced. However, unknown risk types and unknown consequence types do not necessarily mean these events and consequences have never occurred before. It may also be the case that a particular supply chain is unaware because it never experienced such incidents in the past.

The conceptual framework discussed above has certain advantages over the current way of distinguishing between risks and uncertainty in terms of probability distributions. This view is more practical and appropriate for supply chain risk because probability distribution among the types and categories of risk varies a lot and as mentioned above is not readily available in practice. It emphasizes the fact that knowledge about risk and consequence types and the associated attributes will reduce the uncertainty and will help supply chains to manage risk successfully.

(b) Operational risk versus supply chain risk:

Different definitions of supply chain and operational risk that exist within the field of SCRM and ORM are presented in Table 5.

Table 5: Definitions of Operational and Supply Chain Risk

Operational Risk	Supply Chain Risk
The risk of loss, resulting from inadequate or failed internal processes, people and systems, or from external events (Basel Committee, 2001).	Risk in the supply chain centres around the disruption of "flows" between organisations. These flows relate to information, materials, products and money (Jüttner, 2005)
Operational risk can be defined as the risk of loss caused by deficiencies in information systems, business processes or internal controls as a result of either internal or external events (Karow 2002)	Risk in a global supply chain context is defined as the "distribution of performance outcomes of interest expressed in terms of losses, probability, speed of event, speed of losses, the time for detection of the events, and frequency (Manuj & Mentzer, 2008)
The interaction between an uncertain event and internal organisation's processes and/or resources, influencing the core capabilities, quantifiable with a value variation over a time horizon (Silvestri et al. 2009)	An event that adversely affects supply chain operations and hence its desired performance measures, such as chain-wide service levels and responsiveness, as well as cost.(Schoenherr et al. 2008)

It is evident from Table 5 that the definitions of operational risk focus predominantly on internal processes and systems of one organization. On the contrary, supply chain risks by definition focus more on the flows between several organizations. The implication of this difference of concentration between supply chain risk and operational risk is huge because in most cases for supply chain risks, one single organization no longer controls or owns the risk (VanderBok et al. 2007). To further illustrate this point, Figure 2 is presented showing an organization's ecosystem. Any stakeholders listed in Figure 2 can be a source of operational risks. However, for supply chains, the situation is more complicated because all chain members can have their own ecosystem with their own organizational, economic, societal stakeholders and environment. This implies that supply chain risks can arise from supply chain's very own ecosystem consisting of ecosystems of all the supply chain members as portrayed in Figure 3. To further differentiate between these two risks, a conceptual difference between supply chain and operational risk attributes are presented in Table 6.

All these differences between supply chain and operational risk signify that these two fundamentally different risk types should not be categorized under one another.

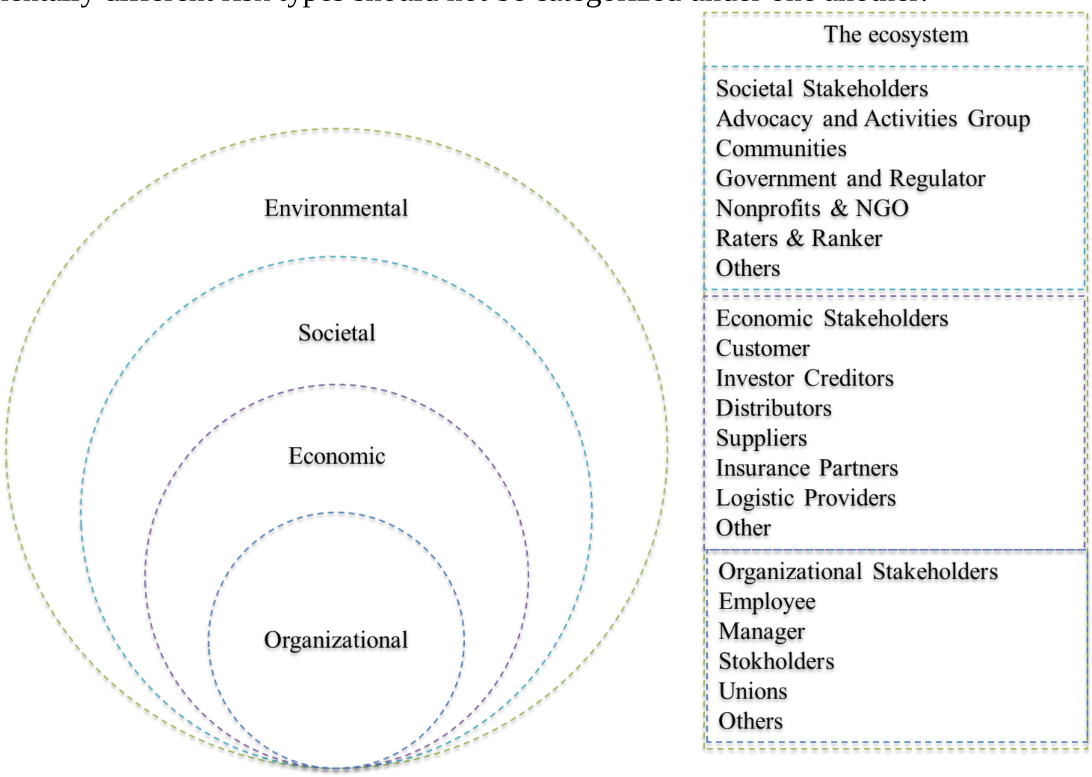

Figure 2: Stakeholders of Organization (Source: Values in Action for Global Responsibility)

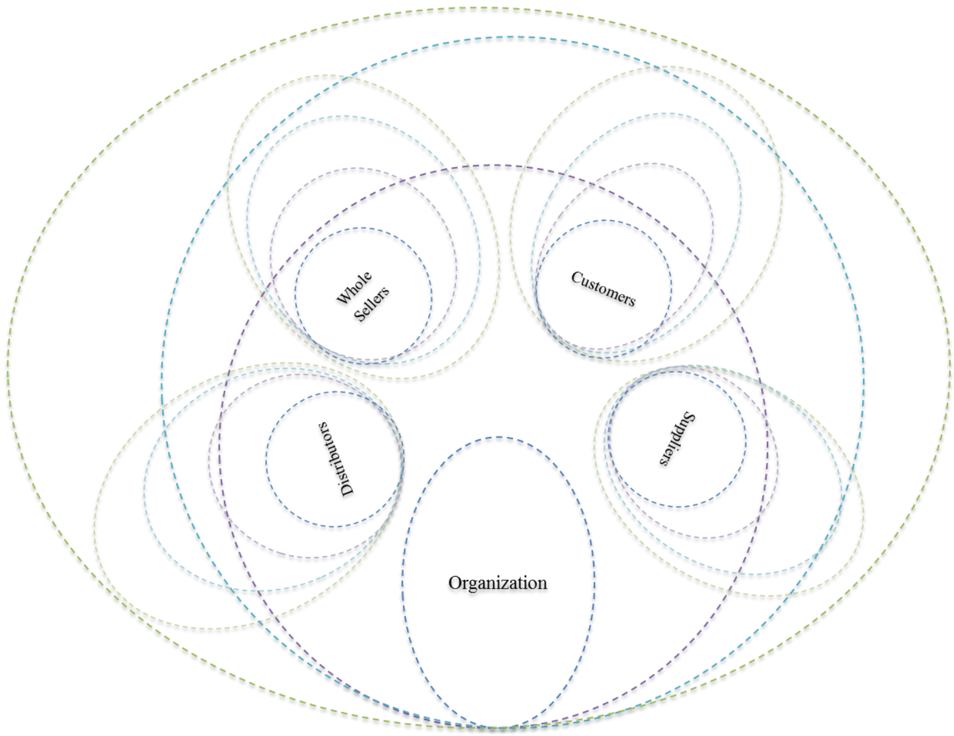

Figure 3: Members of supply chain creating supply chain's ecosystem

Table 6: Differences between Operational and Supply Chain Risks

Risk Attributes	Operational Risk	Supply Chain Risk
People (Source)	Supplier	Suppliers' supplier
Process (Source)	Cross functional	Cross organizational
Environment (Source)	Organization's environment	Suppliers' environment
Consequence	Loss of customers	Out of business (Ericsson case)
Risk Event	Machine breakdown	Supplier delay
Why (Cause)	Own operator's failure	Suppliers' operator failure
What (Cause)	Organization's bankruptcy	Distributors' bankruptcy
When	Mostly predictable	Mostly unpredictable
Where	Often inside organization	Often outside organization
What (Target)	Organization's ecosystem	Supply Chain's Ecosystem
Control	Within organization's control	Outside Organization's control

(c) Illustration of scenario planning as a method for capturing various risk attributes

Because the scenario planning approach is found to have an edge over other methods of identifying risk, an illustration of this approach is presented in Table 7. A comprehensive description of this approach can be found in the article by Dani & Ranganathan, (2008). The case description used to generate scenarios is taken from Brown et al.'s (2011) report on the Earthquake and Tsunami that struck Japan on March 2011. Three different scenarios based on this risk event were generated. Scenario 1 describes the disaster site; scenario 2 describes the effect on the automobile industry; and, scenario 3 describes effect on the Lexus Brand. Several things can be noted from Table 7. First, the "when" row reveals that the consequences occurred are infrequent which is very common for supply chain risks. Second, severities of consequences are different for different scenarios i.e. severity of a nuclear accident is different than that of reduced power capacity or loss of top position by Lexus in the US market. Third, the location of scenario 3 exemplifies how far reaching supply chain disruptions can be. Finally, scenarios 2 and 3 illustrate presence of no formal control to prevent such events. If Japanese automobile industry could predict these scenarios before, they could develop alternate power sources for their production to continue at the normal level. Again, if Lexus had production plants in locations other than Japan, they might not lose the top position in the US Market. Therefore, depending on the industry in concern such scenarios can help to gain important insights about risks and its associated consequence. The scenario planning for Japan earthquake is done here retrospectively, i.e. scenarios are generated after the event, and therefore, consequences are already known. Companies can use similar techniques to generate scenarios from past events in order to predict and plan for future risk events and their associated consequences.

(d) A conceptual framework to reconcile proactive and reactive risk management and resilience

Many empirical studies (Finch, 2004; Dani & Ranganathan, 2008; Blackhurst et al., 2008; CIO Journal 2012) have noted that practitioners are reluctant to identify and manage risks that have never been experienced by them. On top of that, while some researchers are pushing towards adopting a proactive approach (Blackhurst et al., 2008; Ganguly & Guin, 2011), some others (Berg et al. 2008; Dani & Ranganathan, 2008; Braunscheidel & Suresh, 2009; CIO Journal, 2013) are arguing that there needs to be a balance between proactive and reactive measures for

Table 7: Scenarios for Japan Earthquake and Tsunami 2011

Risk Attributes	Scenario 1	Scenario 2	Scenario 3
Risk Event	Earthquake and Tsunami	Earthquake and Tsunami	Earthquake and Tsunami
Source	Nature	Nature	Nature
Consequence	Accident in Fukushima Nuclear Power Plant	Power shortages causing reduced production capacity	Losing Top Position among luxury cars in US
Why (Cause)	Shut down of the power reactor	Accident in Fukushima Nuclear Power Plant	Power shortages causing reduced production capacity
What (Cause)	Design to shut down automatically in case of emergency	Earth Quake and Tsunami	Accident in Fukushima Nuclear Power Plant
When	In 140 years	In 60 years	In 10 Years
Where	Japan	Automotive industries of Japan	US
What (Target)	People, processes, physical assets, environment in Japan	Production process of automobile industries in Japan	Lexus Market in US

Risk Attributes	Scenario 1	Scenario 2	Scenario 3
Control	3 layers of safety control	None available	None Available

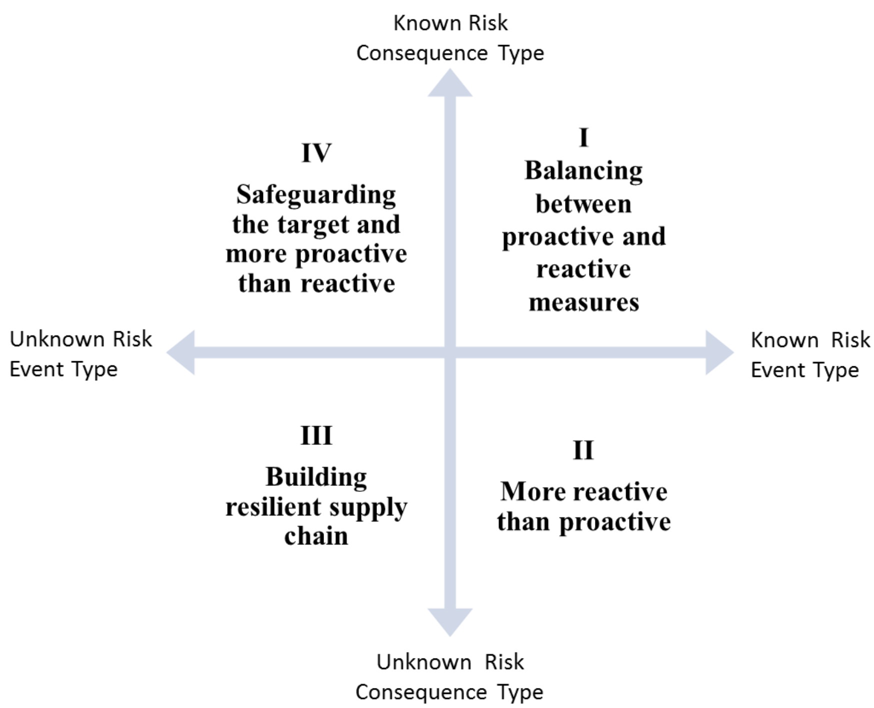

Figure 4: Framework for reconciliation between proactive risk management, reactive risk management and resiliency

managing risks. Another group of researchers suggest that it is more important to be resilient i.e. to build internal capabilities such as flexibility, visibility, collaboration and control (Jüttner et al. 2003; Christopher & Peck, 2005; Sheffi & Rice, 2005; Jüttner & Maklan, 2011) in order to fight risk effectively and minimize its negative impact. To demonstrate that these concepts can work together a conceptual framework is presented in Figure 4 using the known-unknown continuum of risk and consequence type.

In quadrant I, risks and consequences types are known, therefore, risk management strategies should consist of both proactive and reactive measures. Proactive measures include risk identification, risk assessment, risk treatment and reactive measures include response planning, coningency planning and business continuity planning. The concept of building capabilities or being resilient will come into play when there are atleast one unknown: either unknown risk event type (quadrant IV) or unknown cosequence type (quadrant II). For instance, for risks that belong to quadrant II, capacities can be built to track and monitor supply chain events as they happen so that detection can be made as soon as any risk materializes. Building such capacities will also enhable supply chains to react quickly which is required if a supply chain decides to handle risks reactively. For risks that belongs to quadrant IV, where risk event type is known but consequece type is unknown gaining resilience by safeguarding the target or through flexibility is important. Because similar consequences can be caused by many risk events, proactively acting for the known risks and consequences types, can help to safeguard against the unknown consequence types. Quardant III is like a black box where neither risk nor consequence types are known. The reason for this absence of knowledge can be that a particular supply chain has never experienced a risk event or consequence type and so the event is not recognized as a risk. However, no matter what the reasons for this unawareness are, being resilient through internal capacity building will help for such risks because the core idea of resilience is to prepare for the unknown.

Implications:

The implication of this research is of two folds: theoretical and practical. The first theoretical implication is documenting the factors that inhibit supply chain risk identification. These factors suggest that identification of risks depends on a comprehensive understanding of supply chain risk as well as on factors that are inherent to supply chains. It also explains why one size does not fit all when it comes to managing supply chain risk because these inherent factors are different for each supply chain. The second contribution is to enhance understanding of supply chain risk by differentiating risk from uncertainty and supply chain risk from operational risk. It has been illustrated that to reduce uncertainty about a risk and a consequence type, it is important to gain more knowledge by capturing information about various attributes of risk. The third contribution is to list and compare current identification tools/methods/frameworks and highlight the need for approaches that can capture the entire set of attributes of supply chain risks. Therefore, future research should be directed for developing methods that enable supply chains to gain more insights on risks. The fourth contribution is illustrating how scenario planning can be used to identify risks from past events. The final theoretical contribution is to create the reconciliation among proactive risk management, reactive risk management and resilience through a conceptual framework. The framework depicts how these concepts complement each other and hence should be used in combination to manage different supply chain risks effectively.

There are also a significant number of practical implications of this research. First, managers need to understand that risk identification cannot be done in isolation because the success of identification of the supply chain risks depends a lot on the information provided by other supply chain members. Therefore, risk managers need to work closely with suppliers as well as other collaborators such as financial institutions and logistics providers to successfully carry out identification tasks. Second, using the comparisons among different identification methods as a basis, managers can now decide on the most suitable method of risk identification for their specific supply chains. Third, managers are now equipped with the framework for mixing and matching proactive risk measures, reactive risks measures and resilience for managing risks efficiently. Despite these contributions, this paper is not devoid of limitations. One of the limitations of this paper is that the conceptual frameworks developed here depend heavily on the published works by researchers and practitioners. Therefore, future works need to be directed towards the empirical testing of the concepts presented here.

References:

Adhitya, A., Srinivasan, R., & Karimi, I. (2009). Supply Chain Risk Identification Using a HAZOP-Based Approach. *AIChE Journal*, *55*(6), 1447–1463.

Aven, T. (2012). Foundational issues in risk assessment and risk management. *Risk analysis : an official publication of the Society for Risk Analysis*, *32*(10), 1647–56.

AS/NZS 4360 (2004), Handbook: Risk Management Guidelines Companion to AS/NZS 4360:2004, Standards Australia International/Standards New Zealand, Sydney and Wellington

Bandaly, D., Satir, A., Kahyaoglu, Y., & Shanker, L. (2012). Supply chain risk management – I: Conceptualization, framework and planning process. *Risk Management*, *14*(4), 249–271.

Basel Committee (2001), Consultative Document: Operational Risk. Basel Committee on Banking Supervision, Basel

Basu, G., Ben-Hamida, M., Butner, K., & Cope, E. (2008). Supply chain risk management: A delicate balancing act. Retrieved 4th of July 24, 2013 from http://domino.research.ibm.com/library/cyberdig.nsf/papers/2A4BBFF62659E48B852573A1007488DF/$File/rc24415.pdf

Berg, E., Knudsen, D., & Norrman, A. (2008). Assessing performance of supply chain risk management programmes : a tentative approach. *International Journal of Risk Assessment and Managment*, *9*(3), 288–310.

Blackhurst, J. V., Scheibe, K. P., & Johnson, D. J. (2008). Supplier risk assessment and monitoring for the automotive industry. *International Journal of Physical Distribution & Logistics Management*, *38*(2), 143–165.

Bogataj, D., & Bogataj, M. (2007). Measuring the supply chain risk and vulnerability in frequency space. *International Journal of Production Economics*, *108*(1-2), 291–301.

Braunscheidel, M. J., & Suresh, N. C. (2009). The organizational antecedents of a firm's supply chain agility for risk mitigation and response. *Journal of Operations Management*, *27*(2), 119–140.

Brown, B., Held, M., Powers, D., & Wagner, J. (2011). Impact of the disasters in Japan on U . S . manufacturing. *Deloitte Development LLC.* Retrieved July 24, 2013, from http://www.oesa.org/Doc-Vault/Industry-Information-Analysis/Deloitte-Docs/Deloitte-Impact-of-Disasters-in-Japan-on-US-Mfg-Supply-Chain.pdf

Cagliano, A., Marco, A. De, Grimaldi, S., & Rafele, C. (2012). An integrated approach to supply chain risk analysis. *Journal of Risk Research*, *15*(7), 817.–840.

Canbolat, Y. B., Gupta, G., Matera, S., & Chelst, K. (2008). Analysing risk in sourcing design and manufacture of components and sub-systems to emerging markets. *International Journal of Production Research*, *46*(18), 5145–5164.

Chopra, S., & Sodhi, M. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, *46*(1), 52–62.

Christopher, M., & Peck, H. (2005). Building the resilient supply chain. *Harvard business review*, *1*(8), 1-12.

Christopher, M., Peck, H., Rutherford, C., & Jüttner, U. (2003)., Understanding Supply Chain Risk: A Self-Assessment Workbook, Department for Transport-Cranfield University – Cranfield University.

CIO Journal (2012). Command and Control: Managing Supply Chain Risk. Retrieved July 24, 2013 from http://deloitte.wsj.com/cio/2012/11/01/command-and-control-tools-for-managing-supply-chain-risk/

Cohen, M. & Kunreuther, H. (2007). Operations Risk Management: Overview of Paul Kleindorfer's Contributions. *Production and Operations Management*, *16*(5), 525–541.

Cucchiella, F., & Gastaldi, M. (2006). Risk management in supply chain: a real option approach. *Journal of Manufacturing Technology Management*, *17*(6), 700–720.

Dani, S., & Ranganathan, R. (2008). Agility and supply chain uncertainty: a scenario planning perspective. *International Journal of Agile Systems and Management*, *3*(3/4), 178–191.

Deloitte Debates (2013). Truth or Dare: How to Manage Global Supply Chain Risks? Retrieved July 24, 2013 from http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/Consulting/us_consulting_TruthorDareDebate_021913.pdf

Deloitte Debates (2012). The Supplier Risk Link - Fix It Fast If It Breaks – or Do Planned. Retrieved July 24, 2013 from http://www.deloitte.com/view/en_us/us/1b2d773b93912210VgnVCM100000ba42f00aRCRD.htm

Deloitte Insights (2013). Supply Chain Risk Strategies for Emerging Markets. Retrieved July 24, 2013 from http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/AERS/us_aers_foct_gfvc_SupplyChain_01252013.pdf

Deloitte Press Release, (2012). Key Risks Not Being Continually Monitored: Deloitte Survey Retrieved 24 July 2013 from http://www.deloitte.com/view/en_US/us/press/Press-Releases/1b81e5fa92838310VgnVCM1000001956f00aRCRD.htm

Deloitte Survey, (2013). *Executives Face Growing Threats to Their Supply Chain.* Retrieved July 24, 2013 from http://www.deloitte.com/view/en_US/us/press/Press-Releases/e2f4d5e913fac310VgnVCM2000003356f70aRCRD.htm

Faisal, M. N., Banwet, D. K., & Shankar, R. (2007). Information risks management in supply chains: an assessment and mitigation framework. *Journal of Enterprise Information Management*, *20*(6), 677–699.

Finch, P. (2004). Supply chain risk management. *Supply Chain Management: An International Journal*, *9*(2), 183–196.

Ganguly, K. K., & Guin, K. K. (2011). Understanding supply risk in supply chain: a fuzzy framework. *International Journal of Logistics Systems and Management, 8*(3), 267.

Griffis, S. E., & Whipple, J. M. (2012). A Comprehensive Risk Assessment and Evaluation Model: Proposing a Risk Priority Continuum. *Transportation Journal*, *51*(4), 428–451.

Hallikas, J., Virolainen, V.-M., & Tuominen, M. (2002). Risk analysis and assessment in network environments: A dyadic case study. *International Journal of Production Economics*, *78*(1), 45–55.

Harland, C., Brenchley, R., & Walker, H. (2003). Risk in supply networks. *Journal of Purchasing and Supply Management*, *9*(2), 51–62. doi:10.1016/S1478-4092(03)00004-9

Jüttner, U. (2005). Supply chain risk management: Understanding the business requirements from a practitioner perspective. *The International Journal of Logistics Management*, *16*(1), 120–141.

Jüttner, U., & Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management: An International Journal*, *16*(4), 246–259.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Application*, *6*(4), 197–210.

Karow C. 2002 Operations risk: ignore it at your peril. Retrieved 24 July 2013 from http://www.finance-magazine.com/display_article.php?i=3084&pi=130

Kayis, B., & Karningsih, P. D. (2012). SCRIS: A knowledge-based system tool for assisting manufacturing organizations in identifying supply chain risks. *Journal of Manufacturing Technology Management*, *23*(7), 834–852.

Kern, D., Moser, R., Hartmann, E., & Moder, M. (2012). Supply risk management: model development and empirical analysis. *International Journal of Physical Distribution & Logistics Management*, *42*(1), 60–82.
Kersten, W., Hohrath, P., Böger, M., & Singer, C. (2011). A supply chain risk management process. *International Journal of Logistics Systems and Management*, *8*(2), 152–166.
Kleindorfer, P. R., & Saad, G. H. (2005). Managing Disruption Risks in Supply Chains. *Production and Operations Management*, *14*(1), 53–68. doi:10.1111/j.1937-5956.2005.tb00009.x
Klimov, R., & Merkuryev, Y. (2008). Simulation model for supply chain reliability evaluation. *Technological and Economic Development of Economy*, *14*(3), 300–311. Retrieved from http://www.tandfonline.com/doi/abs/10.3846/1392-8619.2008.14.300-311
Knemeyer, A. M., Zinn, W., & Eroglu, C. (2009). Proactive planning for catastrophic events in supply chains. *Journal of Operations Management*, *27*(2), 141–153.
Knight, F. H. (1921). Risk, Uncertainty, and Profit. Boston: Houghton Mifflin Company
Latour (2001) "Trial by Fire: A Blaze in Albuquerque Sets Off Major Crisis for Cell-Phone Giants," *Wall Street Journal*, Jan. 29, 2001, A1.
Lee, C. K. M., Yeung, Y. C., & Hong, Z. (2012). An integrated framework for outsourcing risk management. *Industrial Management & Data Systems*, *112*(4), 541–558.
Li, J., & Hong, S. J. (2007). Towards a New Model of Supply Chain Risk Management: the Cross-Functional Process Mapping Approach. *International Journal of Electronic Customer Relationship Management*, *1*(1), 91-107.
Lin, Y., & Zhou, L. (2011). The impacts of product design changes on supply chain risk: a case study. *International Journal of Physical Distribution & Logistics Management*, *41*(2), 162–186.
Lockamy, A. I., & McCormack, K. (2012). Modeling supplier risks using Bayesian networks. *Industrial Management & Data Systems*, *112*(2), 313–333.
Manikandan, L., Thamaraiselvan, N. and Punniyamoorthy, M. (2011) 'An instrument to assess supply chain risk: establishing content validity', Int. J. Enterprise Network Management, 4(4), 325–343.
Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management. *Journal of Business Logistics*, *29*(1), 133–155.
Mitroff, I. I., & Alpaslan, M. C. (2003). Preparing for evil. Harvard Business School Publishing Corporation
Mukherjee A, 2008, The Spider's Strategy: Creating Networks to Avert Crisis, Create Change, and Really Get Ahead, New Jersey: FT Press
Neiger, D., Rotaru, K., & Churilov, L. (2009). Supply chain risk identification with value-focused process engineering. *Journal of Operations Management*, *27*(2), 154–168.
Norrman, A., & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management*, *34*(5), 434–456.
Oehmen, J., Ziegenbein, A., Alard, R., & Schönsleben, P. (2009). System-oriented supply chain risk management. *Production Planning & Control*, *20*(4), 343–361.
Pavlou, S., & Manthou, V. (2008). Identifying and evaluating unexpected events as sources of supply chain risk. *International Journal of Services and Operations Management*, *4*(5), 604. doi:10.1504/IJSOM.2008.018004
Rao, S., & Goldsby, T. J. (2009). Supply chain risks: a review and typology. *The International Journal of Logistics Management*, *20*(1), 97–123.

Schoenherr, T., Rao Tummala, V. M., & Harrison, T. P. (2008). Assessing supply chain risks with the analytic hierarchy process: Providing decision support for the offshoring decision by a US manufacturing company. *Journal of Purchasing and Supply Management*, *14*(2), 100–111. doi:10.1016/j.pursup.2008.01.008

Sheffi, Y., & Rice, J. (2005). A supply chain view of the resilient enterprise. *MIT Sloan Management Review*, *47*(1), 40–49.

Silvestri, a., Cagno, E., & Trucco, P. (2009). On the anatomy of operational risk. *Industrial Engineering and Engineering Management* 2174–2179.

Singhal, P., Agarwal, G., & Mittal, M. L. (2011). Supply chain risk management : review , classification and future research directions. *International Journal of Business Science and Applied Management*, *6*(3), 15-42.

Sinha, P. R., Whitman, L. E., & Malzahn, D. (2004). Methodology to mitigate supplier risk in an aerospace supply chain. *Supply Chain Management: An International Journal*, *9*(2), 154–168.

Sodhi, M. S., Son, B.-G., & Tang, C. S. (2012). Researchers' Perspectives on Supply Chain Risk Management. *Production and Operations Management*, *21*(1), 1–13.

Sodhi, M. S., & Tang, C. S. (2012). Risk Identification. *Managing Supply Chain Risk.* Vol. 172 Boston, Springer, 13-32.

Svensson, G. (2004). Key areas, causes and contingency planning of corporate vulnerability in supply chains: A qualitative approach. *International Journal of Physical Distribution & Logistics Management*, *34*(9), 728–748.

Tang, O., & Musa, S. N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics*, *133*(1), 25–34.

Thun, J.-H., & Hoenig, D. (2009). An empirical analysis of supply chain risk management in the German automotive industry. *International Journal of Production Economics*, *131 (1)*, 242–249.

Tummala, R., & Schoenherr, T. (2011). Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Management: An International Journal*, *16*(6), 474–483.

Tuncel, G., & Alpan, G. (2010). Risk assessment and management for supply chain networks: A case study. *Computers in Industry*, *61*(3), 250–259. doi:10.1016/j.compind.2009.09.008

VanderBok et al., (2007). Manage Your Supply Chain Risk. Retrieved July 24, 2013 from http://www.sme.org/MEMagazine/Article.aspx?id=20233&taxid=1415

Vilko, J. (2012). *Approaches to supply chain risk management : identification , analysis and control*. PhD dissertation, Lappeenranta, Finland.

Vilko, J., Rumpu, A., & Koivuniemi, J. (2012). An information-exchange perspective on Supply-Chain Risk Management : systemic organisational motives and cognitive barriers. *International Journal of Logistics Management, The*, *12*(4), 460–482.

White, D. (1995). Application of systems thinking to risk management: a review of the literature. *Management Decision*, *33*(10), 35–45.

Wu, T., Blackhurst, J., & Chidambaram, V. (2006). A model for inbound supply risk analysis. *Computers in Industry*, *57*(4), 350–365.

An empirical investigation of the relationship between supply chain capabilities and green logistics

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Abstract

Many studies have hinted the role of supply chain capabilities on green logistics management. Yet, little has been done to empirically examine the relationship. The aim of this study is thus to explore whether possessing certain supply chain capabilities enables the implementation of green logistics practices. We conducted our study by using an online survey instrument that was administered to a random sample of 600 firms in the automotive industry. Our findings validate the positive association between supply chain capabilities and the implementation of green logistics practices. A significant implication of our study may be that organizations seeking competitive advantages through green logistics strategies may need to consider and develop appropriate supply chain capabilities for the successful implementation of green logistics practices.

Keywords: Supply chain capabilities, Green logistics, Capabilities, Resource-based view, Relational view

1. Introduction

Due to the increasing pressure on reducing negative environmental impacts associated with transportation and distribution in logistics, many firms have shifted their attention onto adopting a green logistics management strategy. Previous research has indicated that green logistics can significantly improve environmental performances and lead to competitive positions for a firm (Wu and Dunn, 1995; McKinnon et al., 2010). However, according to the resource based view, the successful adoption of competitive strategies may require the strategic development and deployment of organizational capabilities. In particular, some research has argued that deciding on green strategies, firms should examine their existing resources and capabilities and select those practices that fit with their existing resources and capabilities (Christmann, 2000).

However, little has been done to empirically explore the relationship between capabilities and the implementation of green strategies (Bowen et al., 2001).The purpose of our analysis is thus to fill this research gap by exploring whether certain supply chain capabilities are positively associated with green logistics implementation . In order to achieve our study objective, we applied an online survey instrument that was administered to a random sample of 600 firms in the automotive industry. We start by introducing our theoretical backgrounds and hypotheses in Section 2. Section 3 details our research method. The study results and discussion are presented in Section 4. Section 5 concludes our study and research limitations.

2. Theoretical background and hypotheses

2.1 Supply chain capabilities

The Resource-Based View (RBV) argues that sustained competitive advantages can be achieved by firms possessing valuable, rare, imperfectly imitable, and not substitutable resources and capabilities (Barney, 1991; Dierickx and Cool, 1989; Peteraf, 1993). Olavarrieta and Ellinger (1997) defined capabilities as 'complex bundles of individual skills, assets and accumulated knowledge exercised through organizational processes that enable firms to co-ordinate activities and make use of their resources'. Capabilities' are firm-specific, which cannot easily be transferred from one organization to another, and they can enrich the productivity of a firm's resources (Makadok, 2001). A firm can build and develop strategic new resources and capabilities providing competitive advantages. However, capabilities are path dependent, causally ambiguous and socially complex (Barney, 1991).

An important extension of the RBV is the Relational View (RV), which looks at the specific network of relationships in which a firm is embedded. Of particular importance, the RV argues that a firm's critical resources may extend beyond firm boundaries and may be embedded in inter-organizational routines and processes (Dyer and Singh, 1998). Unique competitive advantages may be achieved as a result of the synergistic combinations of complementary resources and capabilities across firm boundaries (Madhok and Tallman, 1998; Takeishi, 2001). Such resources and capabilities are even more difficult to replicate by competitors because of their idiosyncrasy (Gold et al., 2010). The RV is of particular relevance to supply chain management, which offers a clear theoretic lens to understand the collaboration and coordination mechanisms among supply chain partners from a network perspective (Dyer, 1996; Skjøtt-Larsen, 1999; Chen and Paulraj, 2004). Organizations may regard supply chains as chances to access and acquire complementary resources from other members in the network. For instance, Rungtusanatham et al. (2003) posited that supply chain linkages can be a resource that provides operational performance benefits to a firm, and that supply chain linkages can also be a capability that firms can use to acquire resources that, in turn, generates benefits to the firm's internal operations. By consolidating the views from the literature and the industry, we have identified five generic supply chain capabilities that are of particular relevance to our study. Likewise, these capabilities are path-dependent, casually ambiguous and socially complex (Barney, 1991).

2.1.1 Liaison between SCM and other functions

Liaison between SCM and other business functions provides an essential ingredient for successful SCM (Lambert and Cooper, 2000). For instance, Ellinger (2000) stated that collaboration between departments can ensure delivery of high quality services to customers, which involves the ability to work seamlessly across the 'silos that have characterized organizational structures'. However, a collaborative relationship among different functions is somehow difficult to achieve, because it often involves such issues as interpersonal interactions, company culture and trust (Holland et al., 2000). Therefore, having a collaborative relationship between SCM and other functions is considered be a supply chain capability.

2.1.2 Collaboration and partnership with supply chain members

According to the RV, a partnership mechanism increase economic benefits through more extensive knowledge sharing and lower transaction cost as compared to arms-length relationships (Dyer and Singh, 1998). Likewise, Chen et al. (2004) claimed that committed and collaborative partnerships built upon a longer term orientation, more cooperative information sharing, joint efforts on problem solving, and open communications are associated with superior performance and sustained competitive advantages. Vachon and Klassen (2006) further posited that partnership with suppliers and customers for green project is a capability for effective integration of internal and external know-how and technologies. Thus, this capability generates resource that is difficult to imitate leading in turn to better environmental performance.

2.1.3 Excellent skills/knowledge of SCM personnel

Skills/knowledge involve the ability to effectively manage tasks, search useful information, manipulate IT systems, and form good work relationships, etc. (Briscoe et al., 2001). The skills/knowldge may indeed be difficult to pass on because of the variations in human intelligences, especially if 'intelligence is decomposed into aptitudes for solving differentiated tasks' (Kogut and Zander, 1992). Thus, excellent skills/knowledge of SCM personnel can be a fundamental part of supply chain capabilities. Organizations that possess this valuable capability may also find it easier to implement green strategies.

2.1.4 Supply chain flexibility

A key dimension of supply chain performance is flexibility (Vickery et al., 1999). Lau (1996) defined strategic flexibility as ‘a firm’s ability to respond to uncertainties by adjusting its objectives’. Teece and Pisano (1994) characterized firms that have honed such capability as ‘high flex’. The benefit of supply chain flexibility lies in the ability to facilitate the implementation of meaningful organizational strategies that satisfy customer demands and improve overall firm performance (Duclos et al., 2003). Thus, supply chain flexibility is also considered an important supply chain capability.

2.1.5 IT/IS support

The reliable and effective IT/IS support can be a critical source of supply chain capabilities (Rai et al., 2006), whereby information is readily, continuously and rapidly useable, accessible and shared across the entire supply chain (Daugherty et al., 1995). As discussed by Barney (1991), developing this capability requires successful interweaving IT/IS into the workings of existing business process and practices, and may need the complex interaction with complementary human resources and business resources (Ross et al., 1996). Once the IT/IS support for supply chain capability is effectively developed, competitive advantage can be expected. For instance, Wu et al. (2006) found that through embedding IT in a firm’s supply chain process, IT can facilitate the development of supply chain capabilities which ultimately impact firm performance.

2.2 Green logistics

Green logistics may include forward logistics (inbound and outbound logistics)(Emmett and Sood, 2010) and reverse logistics that deals with recovery, reuse, and recycle (Carter and Ellram, 1998). We separately discuss their respective relationship with supply chain capabilities as follows,

2.2.1 Forward logistics

The major environmental concerns associated with forward logistics may center around the impact of transportation and warehousing activities on the environment (Emmett and Sood, 2010). For instance, McKinnon and Woodburn (1998) studied the cause of traffic growth and its impact on the environment by analyzing the complex interaction between four factors: strategic planning of logistics systems, choice of supplier and distributors, scheduling of product flow, and the management of transport resources. To implement green initiatives in the forward flow, we posit that internal collaborations with careful planning and efficient information sharing among functional departments are fundamentally critical. For instance, with accurate information on demand from sales department, the logistics team can make better material planning and ordering to improve the freight consolidation and cross-docking activities. Second, a broader integration and cooperation with supply network partners may also facilitate green practices in forward logistics. Third, the increasing environmental requirements on logistics activities may lead to the need for a corresponding rise on the level of skills and knowledge among logistics personnel. Finally, we also suppose that readily available and accurate information enabled by effective IT/IS support may also facilitate the forward green logistics realization. Thus, we propose the following hypotheses:

H1a. The level of *'liaison between SCM and other functions'* of a firm is positively related to its implementation of *forward green logistics*.

H1b. The level of *'collaboration and partnership with supply chain members'* of a firm is positively related to its implementation of *forward green logistics*.

H1c. The level of *'excellent skills/knowledge of SCM personnel'* of a firm is positively related to its implementation of *forward green logistics.*

H1d. The level of *'reliable and effective IT/IS support'* of a firm is positively related to its implementation of *forward green logistics.*

2.2.2 Reverse logistics

Reverse logistics (RL) refers to the process whereby firms can become "greener" via recycling, reusing and reducing the amount of material usage (Carter and Ellram, 1998). In order to construct an efficient reverse system, organizations must coordinate their RL activities effectively with transportation modes, transportation services, load, networks and resources (Dowlatshahi, 2000). In addition, the reverse distribution planning, associated inventory control and production planning are extremely complex (Daugherty et al., 2005). Thus, we posit that effective and efficient internal coordination among departments may facilitate the implementation of RL activities. Second, as Srivastava and Srivastava (2006) argued, the coalitions and link with RL partners should be strengthened and expanded in managing effective product returns. Thus, a collaborative and partnership with supply chain members may also be significantly correlated with the successful implementation of RL. Third, the skills/knowledge of SCM personal may too largely impact on the success of RL. Klassen and McLaughlin (1993), for example, argued that the technical skills and capabilities of the research group may affect the development of alternative process for reuse/recycling programs. Finally, supply chain flexibility may also facilitate the implementation of RL. For instance, Vickery et al. (1999) claimed that supply chain flexibility could enable the firm to rapidly reconfigure its supply network structure and introduce new products that are more environmental friendly. Hence, we propose the following hypothesis:

H2a. The level of *'liaison between SCM and other functions'* of a firm is positively related to its implementation of *RL*.

H2b. The level of *'collaboration and partnership with supply chain members'* of a firm is positively related to its implementation of *RL*.

H2c. The level of *'excellent skills/knowledge of SCM personnel'* of a firm is positively related to its implementation of *RL*.

H2d. The level of *'supply chain flexibility'* of a firm is positively related to its implementation of *RL*.

2.3 Environmental proactivity

A proactive corporate environmental stance is often exemplified by going beyond basic compliance with laws and environmental regulations (Aragón-Correa and Sharma, 2003). When firms advocate a more proactive role, they are more likely to deploy their supply chain capabilities to implement green logistics to minimize negative environmental impacts (Klassen and McLaughlin, 1993). For environmental proactivity (EP), we propose the following hypotheses,

H3. The positive associations between *(a)'liaison between SCM and other functions', (b)'collaboration and partnership with supply chain members'*, *(c)'excellent skills/knowledge of SCM personnel'*, and *(d)'reliable and effective IT/IS support'* and *forward green logistics* are stronger in firms with higher EP

H4. The positive associations between *(a)'liaison between SCM and other functions', (b)'collaboration and partnership with supply chain members'*, *(c)'excellent skills/knowledge of SCM personnel'*, and *(d)'supply chain flexibility'* and *RL* are stronger in firms with higher EP

3. Methodology

3.1 Questionnaire development

Following (Creswell, 2009), the questionnaire was developed with a 4-step approach. First, we conducted interviews with academia and industrial managers in the areas of supply chain and logistics management. Then, we developed a draft questionnaire with a pool of measurement items by consolidating the findings from the literatures and the interviews. Third, the draft questionnaire was pre-tested with 5 academics and 6 managers in relevant fields to evaluate clarity, utility and relevancy. The questionnaire was refined based on the feedback received. Fourth, we conducted a pilot test with randomly selected 20 supply chain and logistics managers in the automotive industry. The questionnaire was further revised according to the comments.

3.2 Sample and data collection

We administered our survey to a random sample of 600 firms in the automotive industry. After three-round emailing, we received 122 usable questionnaires for this study (an effective response rate of 20.3%). Non-response bias can be a concern in online survey (Grandcolas et al., 2003). To assess this problem, we compared the early responses to those late ones (Armstrong and Overton, 1977). Results of t-tests revealed that the respondents do not differ significantly ($p < .05$), leading us to conclude that non-response bias was not a major concern in this study.

3.3 Construction of Measures

The measurement was developed following the procedures as suggested by Gerbing and Anderson (1988) and DeVellis (2003). When possible, previously validated measurements were relied upon to improve the reliability and validity of the measures (detailed items and their literature base are available upon request). As large firms normally have more resources than smaller ones, they may be more likely to implement green practices. Thus firm size was introduced as a control variable in the analysis. To test the existence of the common method variance, Harman's single-factor test was performed (Podsakoff and Organ, 1986). The factor analysis of all items revealed 8 factors with eigenvalues greater than 1.0 that accounted for 78.2% of the total variance. The first factor only accounted for 34.7% of the variance (see Appendix).

3.4 Data analysis

To test our hypothesis, we applied moderated hierarchical regression analysis. We centered our independent variables according to Aiken and West (1991). Multicollinearity was tested using the variance inflation factor (VIF). No significant VIF was found in all models (VIF<3) (Cohen and Cohen, 1975).

Table 1 Descriptive statistics

	Mean	s.d.	1	2	3	4	5	6	7	8
1. Size	4.100	2.095	1							
2. Liaison	4.063	0.638	-.013							
3.Collaboration	3.824	0.818	.122	.532**						
4.Skills/Knowledge	3.885	0.666	.164	.410**	.548**					
5.Flexibility	3.913	0.753	.096	.337**	.424**	.445**				
6. IT/IS support	3.459	0.965	-.024	.374**	.439**	.532**	.408**			

7. Forward logistics	3.453	1.077	.247**	.421**	.259**	.330**	.260**	.298**		
8. Reverse logistics	3.202	1.289	.099	.322**	.238**	.343**	.310**	.292**	.573**	
9. EP	4.165	0.746	.231*	.424**	.429**	.426**	.163	.294**	.349**	.213*

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

4. Results and discussion

The descriptive statistics results are shown in Table 1. Table 2 exhibits the regression results. It is obvious that firm size is significantly positively associated with forward green logistics. However, no significant relationship is presented between firm size and RL. For forward logistics, H1a is supported by the results. Thus, firms may need to cultivate a strong internal collaboration between departments in order to successfully implement forward green logistics practices. However, H1b, H1c, and H1d are not supported by the results. For RL, H2a, H2c, and H2d are supported while H2b is not supported by the results. Thus, when firms adopting RL practices, they may need to enhance their internal collaboration, improve the skills/knowledge level among logistics staffs by extensive knowledge learning and sharing, and strive to increase their supply chain flexibility in managing reverse flows. Turning to the moderating effects, H3a-H3c and H4 are not supported by the data. Only a modest relationship is found between the interaction term of IT/IS×EP and forward logistics (β = .305, p < .1, Δ *F-stat* = 1.247). Thus, H3d is partially supported. We may cautiously argue that IT/IS support has a greater effect on forward green logistics implantation in those firms with higher EP.

Table 2 Regression results

Variables entered	Green logistics								
	Forward logistics					Reverse logistics			
	Step 1	Step 2	Step 3	Step 4		Step 1	Step 2	Step 3	Step 4
Intercept	2.931***	2.926***	2.973***	2.969***	*Intercept*	2.953***	3.051***	3.065***	3..028***
Control variables					*Control variables*				
Firm size	.127**	.128**	.117**	.126**	Firm size	.061	.037	.033	.035
Main effects					*Main effects*				
Liaison		.636***	.584***	.577***	Liaison		.443*	.426*	.458*
Collaboration		-.127	-.151	-.134	Collaboration		-.111	-.120	-.122
Skills/knowledge		.178	.141	.133	Skills/knowledge		.401*	.386□	.402□
IT/IS		.165	.160	.103	Flexibility		.288□	.295□	.300□
Moderator					*Moderator*				
EP			.172	.160	EP			.053	.045
Interaction effects					*Interaction effects*				
Liaison × EP				-.253	Liaison × EP				-.369
Collaboration × EP				-.217	Collaboration × EP				.206
Skills/knowledge × EP				.055	Skills/knowledge × EP				.239
IT/IS × EP				.305□	Flexibility × EP				.017
R^2	.061	.275	.285	.316		.010	.183	.183	.205
ΔR^2	.061	.214	.010	.031		.010	.173	.001	.022
Δ*F-stat*	7.829**	8.574***	1.584	1.247		1.180	6.131***	0.091	.752

Main table contains unstandardized coefficients; n = 122

□p ≤ .10; *p ≤.05; ** p ≤ .01; *** p ≤ .001

5. Conclusion and limitations

In this study, we explore whether there is a positive relationship between certain supply chain capabilities and green logistics implementation. Our results validate the positive association and reveal that for respective forward and reverse logistics, specific supply chain capabilities may be required. Therefore, a significant practical implication of our study may be that firms seeking competitive advantages through green logistics strategies may need to consider and develop appropriate supply chain capabilities for its successful implementation. Our study has limitations too. First, we used a cross-section survey design which cannot adequately address the casual relationship between supply chain capabilities and green logistics implementations. Besides, our sample size is relatively small which may affect our finding's generalizability.

References[1]

Aiken, L.S., West, S.G., 1991. Multiple regression: Testing and interpreting interactions. Sage.

Aragón-Correa, J.A., Sharma, S., 2003. A contingent resource-based view of proactive corporate environmental strategy. The Academy of Management Review 71–88.

Armstrong, J., Overton, T., 1977. Estimating nonresponse bias in mail surveys. Journal of Marketing Research 14, 396–402.

Barney, J., 1991. Firm resources and sustained competitive advantage. Journal of Management 17 (1), 99–120.

Bowen, F.E., Cousins, P.D., Lamming, R.C., FARUKT, A.C., 2001. The role of supply management capabilities in green supply. Production and Operations Management 10 (2), 174–189.

Briscoe, G., Dainty, A.R.J., Millett, S., 2001. Construction supply chain partnerships: skills, knowledge and attitudinal requirements. European Journal of Purchasing & Supply Management 7 (4), 243–255.

Carter, C.R., Ellram, L.M., 1998. Reverse logistics: a review of the literature and framework for future investigation. Journal of Business Logistics 19 (1), 85–102.

Chen, I.J., Paulraj, A., 2004. Towards a theory of supply chain management: the constructs and measurements. Journal of Operations Management 22 (2), 119–150.

Christmann, P., 2000. Effects of " best practices" of environmental management on cost advantage: The role of complementary assets. The Academy of Management Journal 43 (4), 663–680.

Cohen, J., Cohen, P., 1975. Applied multiple regression/correlation analysis for the behavioral sciences. Lawrence Erlbaum Associates, New York.

Creswell, J.W., 2009. Research design: Qualitative, quantitative, and mixed methods approaches, third ed. Sage Publications, Inc., Thousand Oaks, California

Daugherty, P.J., Ellinger, A.E., Rogers, D.S., 1995. Information accessibility: customer responsiveness and enhanced performance. International Journal of Physical Distribution & Logistics Management 25 (1), 4–17.

[1] A full list of reference is available upon request

Daugherty, P.J., Richey, R.G., Genchev, S.E., Chen, H., 2005. Reverse logistics: superior performance through focused resource commitments to information technology. Transportation Research

APPENDIX: Factor Analysis and Reliability

Rotated Component Matrix[a]

Survey items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
	EP (α= .929)	Collaboration (α = .900)	Forward logistics (α= .893)	Reverse logistics (α= .878)	IT/IS support (α= .919)	Skills/ knowledge (α = .843)	Flexibility (α = .849)	Liaison (α= .843)
EP2	**.884**							
EP1	**.864**							
EP5	**.859**							
EP4	**.814**							
EP3	**.787**							
EP6	**.743**							
CO3		**.844**						
CO4		**.838**						
CO2		**.778**						
CO1		**.699**						
FL1			**.836**					
FL2			**.835**					
FL4			**.819**					
FL3			**.587**	.468				
RL2				**.880**				
RL1				**.877**				
RL3				**.763**				
IT1					**.883**			
IT2					**.839**			
IT3					**.814**			
SK1						**.784**		
SK4						**.743**		
SK2						**.701**		
SK3						**.641**		
FE2							**.843**	
FE1							**.842**	
FE3							**.763**	
LA2								**.800**
LA1								**.777**
LA3								**.748**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 7 iterations.
*Detailed measurement items and their literature base are available upon request

Adaptation of Emerging Market Firms' Supply Networks in the Context of Internationalisation to Advanced Markets: Development and Test of a Research Approach

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Abstract
This paper suggests a framework for the investigation of how emerging market food firms adapt supply networks in the context of internationalisation to advanced markets. The framework draws on internalisation and institutional theories, and builds on the previous work on supply network adaptation in the context of internationalisation form advanced markets to emerging markets. By operationalizing the proposed framework, the paper suggests an approach for collecting data and drawing conclusions on the nature and patterns of supply network adaptation. The framework and a data collection approach are tested by the means of a pilot case study on an integrated Indian food company. The results suggest the relevance of the research approach. Further research is suggested in the form of a multiple case study.

Keywords: supply networks, adaptation, internationalization, emerging market multinational enterprises, food industry

Introduction
Developing countries play an increasing and relatively more resilient role in the world trade (WTO, 2011). Officially however, there are only five developing or transition economy based multinational enterprises (MNE) on the list of the hundred largest non-financial MNEs ranked by foreign assets (UNCTAD, 2012). Despite the modest presence in the list of the largest companies, many less prominent firms from emerging markets are internationalising to the so called advanced markets for example in Western Europe and North America. The phenomenon itself is not new, as many emerging markets of the past have matured to an advanced state, such as Japan and South Korea, which have given rise to some of the most successful companies in the world. However, the current expansion of emerging market (EM) firms has been suggested to be different, for example as the EM firms are latecomers to internationalisation (Banalieva and Sarathy, 2010). While research on the topic has been done with varying intensity since the 1970s (Wells, 2009), studies that address industry and firm level issues (Wells, 2009), such as will be suggested in the following, remain relevant from both the international business and operations management research point of view.

We specify our research question as follows: *How do emerging market food firms adapt their supply networks in the context of internationalisation to advanced markets?* The research question concerns a situation where a food company from an EM internationalizes to an advanced market (AM) and exerts control over the supply network in the new context. A specific case in this domain may involve any operations or supply network activities in the advanced host market, such as establishment of manufacturing facilities through foreign direct investment (FDI), contract manufacturing, local supply or distribution, or simply exports to the AM. As prior research has confirmed, high performing companies (re)design operations strategies to fit with their environments (Swamidass and Newell, 1987; Ward et al., 1995), and it is therefore paramount for internationalising firms to be able to adapt their supply network configurations for a better interaction with particular host market contexts (Liao et al., 2011; Lorentz and Ghauri, 2010; Nassimbeni and Sartor, 2007; Jiang, 2002). Supply network adaptation has been linked to superior performance (Lee, 2004), however, it does not come without costs. The manner of adaptation, for example reactive or proactive, may significantly affect the level of costs involved and the difficulty of implementation.

The food industry has been chosen as the context of this research due to increasing globalisation of the food supply network (Roth et al., 2008), and due to its characteristics that may simultaneously limit the range of global value chain dispersion (Kittipanya-ngam et al., 2011), implying transfer of entire networks in some subsectors. Furthermore, country market specific institutions influence and regulate the industry (Trienekens and Zuurbier, 2008). These characteristics create a fertile ground for the investigation of supply network adaptation in the context of internationalisation. Srai (2013) also suggests that internationalisation patterns from value chain perspective are influenced by industry.

A framework for analysing supply network adaptation in the internationalisation context

Review of relevant research

Literature that explicitly addresses operations and supply chain adaptation in the internationalisation context is relatively scarce. Whereas contributions from the South-North perspective are non-existing, some work has been done in the North-South –domain. Liao et al. (2011) have investigated supply chain adaptations in the context of establishing foreign owned automotive manufacturing operations in China. Their case study describes the continuous adjustment of the supply management approach, as required by dynamic market fluctuations and evolving government restrictions and regulation. The study emphasises the challenge of balancing compliance with local regulation for local participation and sourcing, and initial scarcity in high quality local supply capacity.

A more general application of the North-South –perspective has been presented by Lorentz et al. (2013). Their research suggests a model for the analysis of the impact of market characteristics on supply networks, with a path from the market characteristics construct (including geography, resources and institutions) to supply network adjustments (configuration dimensions according to Srai and Gregory, 2008), and on to supply network performance implications (dimensions according to Gunasekaran et al., 2001). The case study drew on data from various emerging markets, and focused on discovering firm level events, which were driven by the perceived need to adapt. The events were operationalized as investment or divestment decisions, change projects, changes in priorities, policies, processes etc. that related to the supply network adjustment dimensions. Using the terminology of the internalisation theory (Rugman, 1981), the study of Lorentz et al. (2013) examined the fit of supply network configurations and capabilities (being the actual FSAs or their enablers) with the CSAs in emerging markets, and what kind of adjustments or adaptation were needed.

The key findings of Lorentz et al. (2013) suggest that institutions, and primary and supportive actors may often be considered as potential constraints for fit between market and capabilities, and that these appear to have a dominant role in determining the adjustment of supply network's structural attributes, such as distribution channel length, outsourcing, vertical integration etc. Furthermore, a supply network adjustment categorisation was proposed, suggesting that foreign firms in emerging markets may require supply network related adjustments in terms of (1) network strategy and position, (2) changes to firm boundaries, (3) changes to product mobility, and (4) changes to geographical configuration.

According to Lorentz et al. (2013) the adaptation may go through a life cycle of initial home country convergent practice as firms attempt to roll out AM established practices in a EM context (down-market case; Lessard and Lucea, 2009), later divergent strategies that adapt to emerging market contexts, and finally more convergence as contexts develop. The general phenomenon of dynamics in adaptation may be observed in various settings (North-South, South-North); however, the final phase of home market practice convergence could be non-existing in the South-North context, as this represents the up-market case where EM firms could typically learn and enhance capability platforms as a result of internationalisation to AM and then roll out the new capability platforms in other markets, emerging or advanced (Lessard and Lucea, 2009). The RBV also recognises the life-cycle patterns and dynamics in organisational capabilities over time (Amit and Schoemaker; 1993; Helfat and Peteraf, 2003). The optimal timing of the convergent-divergent-convergent pattern, described by Lorentz et al. (2013), and the exploitation-enhancement-exploitation pattern described by Lessard and Lucea (2009), requires dynamic capabilities from the firm, i.e. "ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments." (Teece et al., 1997).

Adaptation is essentially structural change, which, according to the institutional theory, is mainly driven by isomorphism, i.e. a "process that forces one unit in a population to resemble other units that face the same set of environmental conditions" (DiMaggio and Powell, 1983, 149). The suggested isomorphic mechanisms for change, i.e. coercive, mimetic and normative, provide a useful tool for the analysis of SN configuration adaptation in the context of internationalisation (Davis et al., 2000). Both home and host market exert influence for isomorphism through the SN context and the knowledge base of the managers (primarily EM or AM background) involved in designing the SN configuration. In the internationalisation context, the relative strength of these influences is interesting to consider.

Research framework

Drawing on the insights from extant research on South-North internationalisation and supply network adaptation in the North-South context, we suggest a general framework for analysing supply network adaptation in the internationalisation context, where the level of development between home and host countries is significantly different (Ramamurti, 2009), i.e. the framework can be applied to both the North-South and South-North directions (Figure 1). The framework expands the work of Lorentz et al. (2013), by combining its key elements with the capability platform development model of Lessard and Lucea (2009), and by linking it to the institutional theory of isomorphic change (DiMaggio and Powell, 1983), and is built on the assumption that supply network configuration determines the respective back-end capabilities (Srai and Gregory, 2008), which in turn support and enable the possible front-end FSA of the firm (Rugman, 1981) through supply network performance (Gunasekaran et al., 2001).

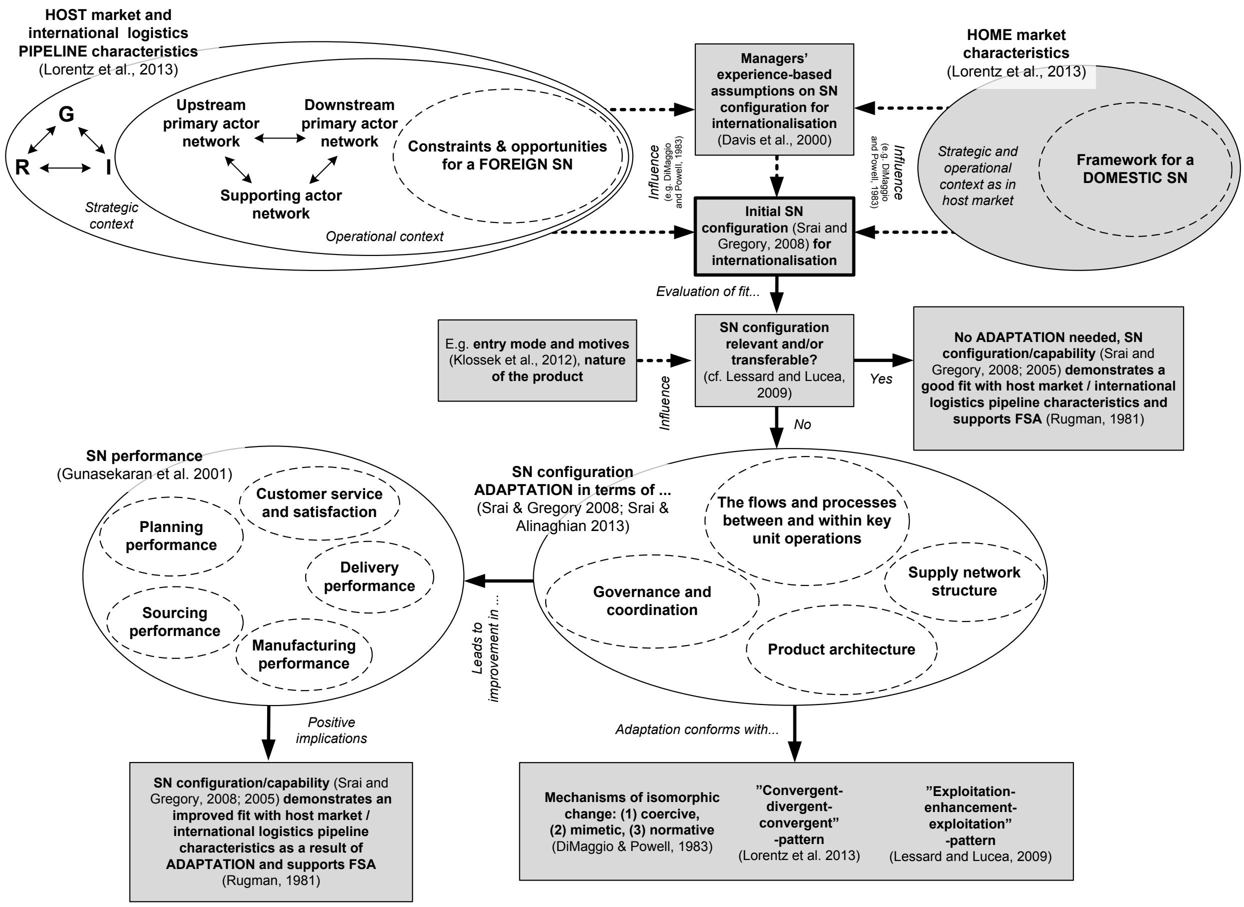

Figure 1 General framework for the analysis of supply network adaptation in the internationalization context (elements with white background represent the original model of Lorentz et al., 2013)

According to Figure 1, home and host market characteristics in terms of the geography, resources and institutions (GRI) dimensions and various actor networks (Lorentz et al., 2013), as well as the international logistics pipeline represent the frameworks that influence managers' experience based assumptions (Davis et al., 2000) for designing SN configurations, and also directly the formation of supply network configurations and capability platforms for internationalisation (Srai and Gregory, 2008; 2005; Lessard and Lucea, 2009), mainly through isomorphic mechanisms (DiMaggio and Powell, 1983). These mechanisms drive configurations to be similar, compatible or fitting either with home or host market, or the international logistics pipeline characteristics. These characteristics may be seen as (1) opportunities, which allow the focal firm's supply network position and performance to improve, and (2) constraints, which create supply network problems, and unless addressed, have negative implications on supply network performance and capabilities. In time, certain characteristics of the market may evolve, presenting themselves at one time as constraints, and as time passes, as opportunities. These drivers can be located in primary (upstream and downstream) or supporting networks of actors (the operational context), and could also be of one of the three strategic contextual dimensions of GRI. The SN configuration and capability platforms may be examined in terms of how well it fits or interacts with the respective host market characteristics and the utilised international logistics pipeline (e.g. in the case of exports). Essentially, we may ask whether the capability-influencing supply network configuration is relevant for the new context and whether it can be transferred successfully across borders (Lessard and Lucea, 2009).

If the relevance and transferability of the supply network configuration and capability platform is met, no supply network adaptation is needed, as the necessary level of fit is achieved and the capability platform supports the FSA. In the opposite case, supply network configuration adaptation takes place through any of the four dimensions identified by Srai and Gregory (2008; see also Srai and Alinaghian, 2013): supply network structure, flow of material and information between and within key unit operations, relationship governance and coordination, and product architecture. These four dimensions provide the framework for the analysis of adaptation in supply network configurations.

It should be noted that several factors may influence SN configuration relevance or transferability, and ultimately, adaptation. From an EM firm's perspective, entry mode, i.e. the decision to enter an AM market for example via exports or through a corporate acquisition of manufacturing (compare with the manufacturing internationalisation concept of Wang and Shi, 2013) may have an impact on the process for achieving SN configuration fit and relevance, as for example in the latter case, an existing AM firm with a new EM owner may continue operations without changes (immediate relevance), with later integration and capability transfer to other plants of the network, whereas the case of market entry through export may involve significant amount of learning, through experiencing the export procedures and local requirements for service and quality. As Lessard and Lucea (2009) suggest, the M&A entry mode may lead to configuration and capability enhancement, and further on to exploitation in other markets and the global network, as here the motivation for internationalisation may be wholly or partly related to strategic asset seeking (cf. Klossek et al., 2012; Wang and Shi, 2013). Furthermore, in the case of a new product, designed for an AM from the outset may impact the initial fit and relevance, with possible isomorphic mechanisms influenced primarily either by home or the host market context. In summary, factors such as mode of entry or internationalisation and phase in the product's life cycle may influence whether and how adaptation ultimately takes place.

Further, while delivery performance has been identified as a key contributor to overall firm performance (Fawcett et al., 1997), it is desirable in this context to differentiate changes in a variety of supply network key performance indicators that result from configuration adaptation and the resultant changes in capabilities, namely in terms of sourcing, manufacturing, delivering, planning and customer service (Gunasekaran et al., 2001). Positive performance implications signal an improved fit of configurations and resultant capabilities with the characteristics of host market and the international logistics pipeline, and better back-end support of the FSA. In contrast to these practical implications, the adaptation may from theoretical perspective conform to the three mechanisms of isomorphic change (DiMaggio and Powell, 1983), and/or the convergent-divergent-convergent –adaptation pattern (Lorentz et al., 2013) and/or the exploitation-enhancement-exploitation –adaptation pattern (Lessard and Lucea, 2009). The latter may be detected especially in the cases where the driving motivation for internationalisation is of the strategic asset -seeking kind.

Proposition development: EM firms' food supply network adaptation in AMs

In this section, we develop propositions on how EM food supply network configurations are adapted South-North (up-market) context. We focus on the differences between archetypal food supply chains and agrifood systems found in AM and EM context, and consider the implications to home market based configurations and capability platforms (top part of Figure

1). After contrasting the AM and EM food supply networks, we cover the possible adaptation implications in terms of each of the dimension of the supply network configuration construct (Srai and Gregory, 2008; Figure 1), from the EM firm point of view.

Characteristics of AM food supply networks

Food supply networks involve many actors in the vertically arranged tiers, who may potentially extend their reach and by-pass tiers. Supply network structures observed in practice depend on food product characteristics (e.g. value added foods and commodity foods) and actors' market power (Roth et al., 2008).

In AMs, food supply networks are usually characterised by consolidated distribution (Roth et al., 2008), i.e. large, and even international retail firms serving the consumer (Dobson et al., 2003; Brookes, 1995), but simultaneously by the emergence of new alternative systems of food provision that may emphasise local sources and quality (Watts et al., 2005; Renting et al., 2003). Prominent retail firms in the supply network imply high bargaining power, means to develop efficient logistics systems and the ability to project significant investments into technologies that support streamlined information and material flows (Dobson et al., 2003; Kelepouris et al., 2007). In order to plan the execution of supply and replenishment in the face of typically uncertain demand coupled with perishability and shelf-life limitations of many food products, retailer driven food supply networks in AM seek to collaborate and coordinate in order to improve performance (Duffy and Fearne, 2004). In practice, vendor management inventory solutions, joint planning arrangements such as the CPFR, or novel ways of contracting may be implemented in the food supply network (Holweg et al., 2005; Ahumada and Villalobos, 2009). Accordingly, participation in the retailers' supply networks in AMs also requires investments and organisational adaptation from the supplying actors (Waller et al., 1999), i.e. the making of relationship specific investments, if for example the CPFR arrangement is of advanced type with high levels of information exchange (Skjoett-Larsen et al., 2003). Indeed, Matopolulos et al. (2007) show the importance of such basic antecedents as trust, power, dependence, and risk/reward sharing in establishing and maintaining collaborative supply chain relationships in the food sector.

Furthermore, the ultimately AM consumer driven trend to implement both private and public standards for food safety and quality in the supply network has increased the costs of certification, and is increasing the pressure on manufacturers' and other actors' profits (Trienekens and Zuurbier, 2008). What may have initially lead to higher producer prices, as a result of higher perceived quality, tend to become conventional and an order qualifying factor for retailers (Réviron and Chappuis, 2005). Roth et al. (2008) also suggest that the consolidation of the retail sector leads to increase in the commoditisation of the food industry in general.

The requirement for traceability and quality assurance in AMs extends all the way from fork to farm, involving the entire food system at the upstream side as well. Traceability requires both organisational and technical resources from the involved firms (Engelseth, 2009), and is especially relevant for value added food products which have characteristics, or content and process attributes, that are important and difficult to observe for the consumer, such as of organic farming or the employed processing techniques (i.e. credence attributes; Roth et al., 2008). Close relationships, with trust and transparency, have traditionally facilitated traceability and assurance of quality. However, Buhr (2003) suggests traceability enabling information systems are often required, as an alternative to product labeling, repeat purchasing, and certification, and that these lead to tighter vertical relationships and more hierarchical governance structures.

In addition to traceability, drivers for closer vertical coordination in the AM agro-industrial systems include the aims to reduce transaction costs, to reduce risk, to enhance the ability to innovate and to differentiate, to enable a more efficient exchange of information and organisational structures, and to improve market positions (Ziggers and Trienekens, 1999; see also Hobbs and Young, 2000). Partnership arrangements imply that the capability to manage external assets is more important for food supply network actors than asset ownership, and that market exit and entry barriers become higher (Ziggers and Trienekens, 1999).

In terms of food manufacturing processes, state of the art technologies and process designs may be associated with the general AM environment, at least in the case of leading firms and the competition that the EM firms would have to face as they internationalise. According to Mahalik and Nambiar (2010) significant level of automation is applied in the two main stages of the food production process, namely processing and packaging. In the latter, sustainability requirements drive the proliferation of environmentally friendly materials, and technological advancement enables the use of smart packaging, new protective materials and sensors. At the manufacturing system side, robotics and automation, fieldbus technologies, in-line inspection methods and anti-microbial coating of handling equipment are available for leading food processors (Mahalik and Nambiar, 2010) who strive to maintain competitiveness and market positions. Advanced operations management concepts, such as lean principles (i.e. reduction of waste, improvement of quality and service; Taylor, 2005) mass customisation (van Hoek, 1997), theory of constraints (Spencer (2000), and supply chain management (van der Vorst et al., 1998) can, and have been applied in the AM food industry context. In order to deal with demand uncertainty, advanced planning concepts have been developed specifically for, and implemented in the food industry (Christou and Ponis, 2008). However, the nature of the industry, i.e. the need for excess capacity and low profit margins, often deter implementation of leading practices (Mahalik and Nambiar, 2010).

Functional food supply chains require careful control of material logistics in the entire pipeline, due to the possibly perishable nature of the transported products. The institutional environment in AMs facilitates the development of relevant and competitive service industries with adequate and specialised capacity for food transportation. As a result, outsourcing of business functions outside the core competence of the firm, comprising often sets or individual logistics activities, may take place. Wilding and Juriado (2004) found that outsourcing in the European consumer good industry is heavily service driven (in contrast to cost alone) and focused on the traditional logistics function, such as transport and freight forwarding; however, AM based leading companies outsource also order processing, invoicing and logistics information systems (Solakivi et al., 2011). The generally transport focused behaviour is probably explained by the food processing industry specific results of Hsiao et al. (2010), which suggest that positive outsourcing related performance outcomes are elusive, and that service performance improved markedly only in the context of high demand complexity and outsourced distribution network management. Interestingly, consumer good firms point out soft issues, such as cultural incompatibility and poor communication, as drivers of failure in outsourcing performance and partnership (Wilding and Juriado, 2004).

In summary, AM food supply networks demonstrate high level of competition, sensitive consumers, consolidated distribution channels, shorter or more direct supply chains, prevalence for partnerships along with a full range of other governance forms (Williamson, 1973), outsourcing of non-core functions and activities, both formal and informal institutions (North, 1990) that facilitate operations planning, quality and safety of products in the food supply network, and use of state-of-the-art production technologies and processes. From the point of view of suppliers, these imply powerful customers and often low profit margins, relationship specific investments in technologies, processes and organisations, investments into achieving compliance with institutions and new technologies, and emphasis of relationship management over asset management, i.e. capabilities in managing external resources. Furthermore, the AM food supply networks operate in the context of appropriate transport and communication infrastructure, capable support actors, such as logistics service providers (LSP), and stable institutions.

Characteristics of EM food supply networks

In contrast to AM, the EM food supply networks can be characterised by definition to be more evolving and in a stage of development that precedes the stages typically observed in AMs. EMs and the international logistics pipelines leading to AMs may have deficiencies in infrastructure, capacity and capabilities of LSPs, as well as in the quality and stability of institutions regulating the supply chain (e.g. Arvis et al., 2012). Ordinary logistics challenges, such as related to maintaining the cold chain in the food logistics context, can be compounded by resource limitations in EMs (Salin and Nayga, 2003). EM firms' production technologies and process designs may be less than optimal, or more manual due to the potential labour cost related CSA, as these take into account the typically higher level of uncertainty with additional safety inventory (Prasad et al., 2005; Gulyani, 2001; Handfield and Withers, 1993). In addition, all these factors may be in a state of change. Indeed, much of the literature on agri-food systems or supply chains in developing countries and emerging markets, observes some particular changes in the network, related to for example economic transition (Gorton et al., 2006) or globalisation in general (Reardon et al., 2003), and the respective effects and wider implications of these changes.

For example, as food sourcing extends from developed markets to developing countries and EMs, the requirements for quality and safety lead to the predominant use of large-scale and efficient producers and farms in the EMs (Barrett et al., 1999) spurring their growth. In the same vein, as quality focused modern retail formats, such as the supermarket, permeate the EMs (Coe and Hess, 2005; Kaynak and Cavusgil, 1982), traditional small scale farmers find it difficult and costly (additional processing phases may have to added) to participate in these new supply chains with large order volumes, specialised wholesalers and strict standards (Boselie et al., 2003; Weatherspoon and Reardon, 2003), requiring trust based relationship, risk management and supplier cooperation as facilitators (Blandon et al., 2009). Coe and Hess (2005) suggests that the retailer internationalisation induced restructuring in EM food supply networks can be characterised as involving centralisation of procurement, logistics upgrading, supply network shortening with new intermediaries, use of quasi-formal contracts, and the development of private standards. The consequent supply network "shakeout" favours large suppliers, leading to polarisation of the supply base. Cadilhon et al. (2006) suggest that while capability upgrading across the system takes place, as supermarkets gain market share, policy makers should support traditional supply chains, in order to meet demand of all the various consumer segments.

Therefore, due to the internationalisation and domestic emergence of retailing and the heterogeneous consumer base (Mergenthaler et al., 2009), distribution and supply chains in EMs will continue to demonstrate a range of alternative network structures (Humphrey, 2007; Kaynak and Cavusgil, 1982), from traditional, fragmented and multitier channels ending in wholesale markets and small shops, to more consolidated and shorter channels with large and international retailers at the end (Lorentz et al., 2007). This variety will extend to farming as well, with large and small farms coexisting. Major EM food manufacturers typically may have to deal with both the detail and dynamic complexity of being involved in these networks (cf. Bozarth et al., 2009).

One of the distinguishing features of the new supermarket led supply chains in EMs, with such profound impact on the food supply network structure through exclusion and inclusions of actors and the potential upgrading of local industrial clusters (Humphrey and Scmitz, 2002; Dolan and Humphrey, 2000), is the requirement for quality, safety and sustainability standard compliance, along with other more operations related performance requirements such as cost, delivery and product variety (Dolan and Humphrey, 2000). Having been in the hands of the state in the command economies now undergoing transition and liberalisation, the vertical coordination for quality and safety was disrupted and private institutions have gradually emerged to fill in the void (Swinnen and Maertens, 2007). In addition to the diversity and evolution of standards (Henson and Humphrey, 2010; Henson et al., 2005), their existence alone may serve as considerable barriers for typical EM firms attempting to export and enter AMs, with economic effects manifested in both the macro and micro levels in the home market (Henson et al., 2005). Small firms have been shown to be able to cope with varying compliance requirements to some degree; however, organisational learning, responsive supply chains and control systems that are multi-tiered and involve incentives and penalties, are required to achieve this, a feat that draws to significant degree on support from policy makers (Henson et al., 2005). However, food safety standards may also be seen as catalysts for capacity upgrading, market positioning and supply chain coordination for the most capable EM firms (Henson and Jaffee, 2008; Muradian and Pelupessy, 2005). According to Humphreys and Schmitz (2002), food exports from EMs to AMs are often governed through quasi-hierarchies, i.e. AM buyers set the parameters for product designs and processes in order to manage the risk of noncompliance. This facilitates production upgrading, but not movement towards more value-adding activities, as strategic intent (dynamic capabilities) and substantial investments are required in the latter.

In summary, EM food supply networks demonstrate heterogeneous consumer segments and channels from distribution point of view, heterogeneous supply base, full range of relationship governance forms with predominance of quasi-hierarchies in the modern and export supply networks, less opportunities for outsourcing of non-core functions and activities, emerging but not yet predominant use of formal and informal institutions that facilitate quality and safety of products in some segments of the food supply network, and relatively more manual and less technologically advanced production processes. From the point of view of suppliers, significant entry barriers to the new or export supply chains exist, requiring compliance and voluntary upgrading related investments into technologies and processes designs, or in other words, adaptation. In short, change, complexity (detail and dynamic) and deficiencies in various capacities and capabilities characterise the EM food supply network.

Propositions on EM firms' adaptation of food supply network configurations in AMs

How do the differences in AM and EM characteristics and food supply networks translate into configuration adaptation among the EM firms who internationalise into AMs? Drawing on the supply network configuration construct and its four dimensions defined by Srai and Gregory (2008), we propose some typical adaptations in terms of the configuration and its capability implications.

The *structure* related dimension of the supply network configuration construct is defined for example through the following concepts: network tier structure and shape, composition, ownership, levels of vertical and horizontal integration, location, geographic dispersion and configuration of the value chain, complexity etc. (Srai and Gregory, 2008, 394; see also Srai and Alinaghian, 2013). The previous elaborations on the characteristics of these two archetypal markets and the respective food supply networks suggest that EM firms would have to, on average, employ shorter supply chains and direct engagement with powerful retailers, or in other words, there are fewer echelons in the supply chain. As AMs are typically characterised by stable institutions that enable exchange of complex goods and services, and by the availability specialised service capacity, the internationalising EM firms may be able to outsource to a greater extent the activities that have been preferred to have been kept in-house at the home market due to uncertainty and governance problems. This may imply a greater role for the purchasing function in the firm, which should develop capabilities for managing external resources, or for purchasing of services, including defining the service, contracting for service delivery, and measuring service performance. The mode of internationalisation determines the extent to which greater levels of outsourcing is implemented in the value chain. Furthermore, the product value chain may be geographically reconfigured for competitiveness, depending for example on the interaction of the nature of food product value chain steps (e.g. labour intensity and feasibility for automation), and home or host CSAs (e.g. labour costs, available technologies), making export supply networks to other EMs and AMs different. The powerful retailers may also seek to transfer slices of the value chain to the supplier, through a push for the implementation of VMI or in-store replenishment (Waller et al., 1999), potentially resulting in threats to equitable collaborative relationships (Corsten and Kumar, 2005). We state the following proposition:

P1: In the context of internationalising to AMs, EM food firms' adaptation of supply network configuration is characterised by (a) more direct customer relationships, with retail key accounts managing secondary distribution entirely, (b) greater extent of outsourcing and external resource management, and (c) reconfiguration and extension of the product value chain, for the purposes of exploiting CSAs and achieving improved delivery performance.

The dimension related to the *flow* of material and information between and within key unit operations is defined through the following concepts: value and non-value adding activities, process steps, optimum sequence, levels of flexibility, process infrastructure and enabling IT systems, replenishment models, decoupling point (Srai and Gregory, 2008, 394; Srai and Alinaghian, 2013). The benefit of drawing on the CSA of low labour costs may be lost in some modes of internationalisation, and EM food manufacturers may have to, on average, adapt the supply network configuration by employing higher levels of process automation, as well as by changing process designs accordingly. Requirements for advanced packaging materials may also imply adaptations to process technology and step sequence. These may also have to be changed in order to comply with the specifications imposed by the powerful retail customers, and driven by regulatory standards and voluntary practices in the AM based industry (e.g. Roth et al., 2008). Consequently, capabilities in food processing technology and quality and risk management may have to be developed. Powerful retailer key accounts also demand efficient and effective logistics processes for replenishment (Dobson et al., 2003). In the case of exports, the potentially long international logistics pipeline implies longer lead times and uncertainties, requiring the examination of processes and inventory policies, and development of capabilities in managing international logistics. We state the following proposition:

P2: In the context of internationalising to AMs, EM food firms' adaptation of supply network configuration is characterised by (a) greater extent of process automation and advanced technology implementation, (b) seeking of process compliance with standards and performance targets, and (c) changes in process design for replenishment, order fulfilment and international logistics.

The dimension related to supply network configuration adaptation in terms of role, inter-*relationships*, and governance between key network partners is defined through the following concepts: the nature of interactions or transactions, coordination, partner roles, governance and trust (Srai and Gregory, 2008, 394; Srai and Alinaghian, 2013). With direct engagement with powerful AM retailers, the EM food manufacturers may on average have to adapt from market transactions and supplier driven networks to quasi-hierarchical and retailer dominated relationships, where systemic power is projected on the supply network (Brookes, 1995), oriented towards ensuring product quality, safety and process compliance. Whereas transactional relationships may dominate for example in contract manufacturing of commodity products, in some cases relationships may resemble more balanced partnerships, oriented towards coordination and capability development of the EM supplier itself (value-added products with credence attributes).

Indeed, Corsten and Kumar (2005) show that small suppliers, and perhaps EM suppliers as well, can upgrade their capabilities by entering into collaborative relationships with leading retailers. Relevant capability requirements then include cross-cultural competence, comprising personal attributes and skills, as well as cultural knowledge (Johnson et al., 2006), developed across multiple functions in order to enable broad-based and supply chain management oriented relationships (i.e. diamond vs. bowtie relationships; McAfee et al., 2002). To this effect, customer relationship management capabilities are also needed for managing multiple key relationships in the network, and in order to enable upgrading through learning. Specifically, these may include such second order constructs as relationship infrastructure capability, relationship learning capability, and relationship behavioural capability (Jarratt, 2004).

Direct key account relationships with powerful retailers may require perhaps a focused effort to improve logistics service and order fulfilment cycle performance in general. The AM supply networks may also require a greater extent of coordination and integration for balancing supply and demand, locating inventory in the supply chain, as well as for achieving traceability and compliance for credence attributes (Roth et al., 2008), exceeding the level experienced by EM firms at the home market. This implies a need for capabilities that enable participation in the inter-organisational efforts to increase visibility and compliance, and to balance supply and demand by developing the organisation, processes and systems for sales and operations planning (S&OP) or vendor managed inventory (VMI; Richey et al., 2008).We state the following proposition:

P3: In the context of internationalising to AMs, EM food firms' adaptation of supply network configuration is characterised by (a) retailer driven quasi-hierarchical and long-term contract based relationships, with call-off arrangements, as well as (b) greater extent of coordination for efficient logistics, supply-demand balancing and compliance for product credence attributes, implying a range of inter-firm relationship types from broad-based to transactional.

The dimension related to the adaptation in terms of *value-structure or architecture* (Ulrich, 1995) of the product or service is defined through the following concepts: product composition and structure (including components, sub-assembly, platforms, modularity), SKUs, products as spares, and through-life support and services (Srai and Gregory, 2008, 394; Srai and Alinaghian, 2013). The challenges of the international logistics pipeline may in some cases lead to adaptation of the architecture of the product for greater mobility (Kittipanya-ngam et al., 2011), in order to arrange for most economical transport that simultaneously supports other goals as well, such as quality and delivery performance in general (e.g. packaging, attribute change). Retailers may also benefit from the proliferation of suppliers' product variants (also with shorter life-cycles, and extensions to service components such as for product merchandising), which are aimed at catering for promotions and attractive product offerings in competitive consumer markets (Ailawadi, 2001). All these require advanced supply chain management capabilities from the supplier, in order to take into consideration the characteristics of the international logistics pipeline from product architecture point of view, to implement additional process steps for product enhancement and service provision, as well as to manage many and even key account specific product variants and introductions. We state the following proposition:

P4: In the context of internationalising to AMs, EM food firms' adaptation of supply network configuration is characterised by (a) general and key account specific extension of product variants and offerings, (b) shortening of product lifecycles, and (c) changes in product and packaging attributes for greater mobility.

In summary, we propose that the internationalisation of EM food firms to AM markets entails significant levels of supply network configuration adaptation, driven mainly by the AM retailers' ability to project systemic power in the supply network and by institutions aimed at matching supply with demand and ensuring quality, safety and sustainability. The configuration adaptation is characterised in a broad terms by shifts towards increasingly network-like way of operation (management of key accounts, partnerships, outsourcing), upgrading of process technologies and management, and extension and changes of product architecture for value and mobility. In terms of capability requirements, these adaptations imply development of such areas as management of relationships and external resources, advanced supply chain concepts for demand-supply planning and complexity management, quality and risk management, as well as product design. Generally, EM firms have been conditioned in their home market context to develop dynamic capabilities, and so the propensity for adaptation may be higher in comparison to AM firms.

The propositions presented here reflect the EM firms' general internationalisation motivations, geared often towards upgrading or enhancement of capabilities (e.g. Cuervo-Cazurra, 2013). Supply network configuration adaptation and the resulting capabilities may be similar in nature, regardless of whether this is the actual underlying motivation for market entry, as in most cases this is hardly the underlying motivation. The nature of adaptation is also suggested to depend on the mode of internationalisation, as exports and a greenfield investment to a processing facility clearly imply different outcomes. Although the propositions presented here are quite general in nature, they reflect the current knowledge base on the topic of this research, combined from an interdisciplinary body of literature, and, importantly, they facilitate the subsequent analysis and discussion of empirical data.

Illustrative case study of an EM firm's supply network adaptation in terms of AM business

Research approach

This research is exploratory in nature and draws on the case study method where a contemporary phenomenon is investigated within its real-life context, through a "how" based inquiry (Yin, 2003). However, in order to focus the data collection effort, a literature-based model with relevant constructs, and food industry specific propositions have been derived. These relate to the a priori constructs in inductive case study approach, as suggested by Eisenhardt (1989).

The target of the research, i.e. evolving SNs, being a complex phenomenon, implies challenges for research design. As such, the case study strategy is described as being well equipped in handling dynamics and change processes embedded in research contexts (Eisenhardt, 1989; Yin, 2003). However, Halinen and Törnroos (2005) pointed out four problems for conducting case study research on inter-organisational networks: problem of network boundaries, problem of complexity, problem of time and problem of case comparisons. These issues are briefly addressed in the context of this research.

The boundaries between the firm, networks and its environments have been described as very much diffuse (e.g. Anderson et al., 1994). Networks may span across several tiers and industries, and therefore, for the purposes of analysis, the horizon of the research target should be limited. Instead of attempting a holistic investigation across the whole SN, the focal actor and product perspective is taken, incorporating intra-firm considerations, as well as the firm's upstream and downstream relationships from focal actor's perspective (Halinen and Törnroos, 2005). The food product has been chosen as the unit of analysis. Data collection is mostly retrospective, in contrast to longitudinal studies where empirical intervention takes place over time. In the eventual multiple case study research, cross-case comparison will be attempted, for the purposes of descriptive theory generation (Yin, 2003), such as SN adaptation typologies (Christensen, 2006). However, in this particular paper, we limit data collection for a single case, in order to test the research approach and instrument. The network boundary-setting and focus of the research on products, reduces complexity and facilitates comparison, in contrast to a situation where holistically described networks serve as the unit of analysis.

Data collection and analysis

The data collection process for the research starts from the identification of data collection targets (companies), and proceeds to identify relevant cases (products) to be analysed. A purposive sampling of cases for maximum variation will be attempted during the planned research process, i.e. we purposefully select cases with a wide range of variation in terms of the dimensions of interest and therefore plan for documenting both unique and common variations that emerge in different conditions (Patton, 1990). This will also enable us to identify common patterns that appear across cases. However, this particular paper only illustrates the planned research process and instrument through as single case study, suggested to represent a typical case.

For the eventual larger data set, cases (products) may be drawn from food manufacturing companies that originate from emerging markets, defined broadly as the BRIC countries or any developing countries, which internationalise to AMs. Cases may range from internationalisation modes such as establishment of manufacturing facilities through foreign direct investment (FDI), contract manufacturing in EM for AM market, or exports to the AM. We seek to incorporate a wide range of food subsectors, different kinds of food products (e.g. value added foods and commodity foods; Roth et al., 2008), products designed originally for both EM (established) and AM (new), as well as firms of different size and degrees of market position (e.g. both large multinationals, if any, as well as niche player SMEs) in to the eventual multiple case study data set.

The instrument for data collection (interview guideline) is presented in Appendix A. The data collection starts with inquiries about the nature of the product, competitive strategy and the involved managers' background (questions 1-4). The remainder of the questions are arranged so that each of the SN configuration dimensions (Srai and Gregory, 2008) is addressed in turn. The literature-based propositions aid in limiting and focusing the scope of data collection effort to the most likely areas of SN configuration adaptation (see focus areas per dimension in Appendix A). Each of the focus areas, or subpropositions (a through c) is covered by first inquiring the respondent for host market configuration characteristics, then for any changes in this area during the internationalisation process or differences to the home market, respective drivers, the process for possible adaptation, and finally, the performance and capability implications of the possible adaptation, if any (questions 6 through 18). In practice, many of the questions may be covered relatively fast as no adaptation may have taken place. The interview guideline is also flexible in the sense that it can take into account situations such as where a product has been originally designed for the EM and now exported or produced in an AM, or a situation where the product has been originally designed for the AM in contract manufacturing situation for example. The matrix in Appendix A, populated with interview questions, is used also in the presentation of condensed data in a data display format, allowing within and cross-case analyses (Miles and Huberman, 1994), and a degree of transparency.

The research may require data on both market and SN configuration characteristics in two geographically separate locations. The ideal respondent has knowledge of both locations and SNs, having for example managed the SN for home market, and now being responsible also for exports, or only for foreign production as an expatriate manager. However, a manager may lack knowledge of the home market, but has been involved, or has knowledge of, about the entire internationalisation process of the product, therefore being able to describe changes in configuration during the internationalisation process. However, several respondents may also have to be interviewed in order to draw a full picture of the case. For this paper, we present the results from a single case, with data collection based on interviews, intensive 18-month participation in the internationalisation and adaptation process, as well as company documents (internal and public, such as the website).

Case study background and results

The pilot case is about preserved and packed gherkins (pickles), processed and marketed by an Indian multinational company in preserved vegetable business, with an annual turnover of 150 million USD (see also condensed case description in the data display in Appendix B). The company is a subsidiary of a diversified Indian business conglomerate, with approximate parent total turnover of 4 billion USD. During the 1990s, the growth of the case company was driven by increasing international sales and internal manufacturing competence, whereas corporate acquisitions during late 1990s and throughout the 2000s for key account business and manufacturing capacity solidified its international business throughout Europe, Far East and the North America, with business units and legacy operations footprint in Belgium, Holland, Hungary, Turkey, and India. The initial legacy footprint was designed so that Eastern European supply served European markets, and Indian supply served the US, Canadian and the Far East markets. Until recently, there has been no "home market" for packed and preserved gherkins in India; however, with urbanisation and proliferation of modern retailing and fast-food catering, a domestic supply chain is being developed as well.

The case describes the evolving international SN configuration for gherkins mainly grown in Southern India, during the internationalisation process of the product and the company in general.

The entire product range of the company is based on such items as gherkins (case product), relish, pickled onions, cherries, jalapeno peppers, paprika, capers, and sweet corn. The company operates mainly a contract manufacturing “seed-to-shelf” model, by identifying and developing the most appropriate seed varieties, growing in wholly-owned farms or contracting crops by specifications to a network comprising tens of thousands of farmers, processing and packaging the produce in in-house and partners’ international facilities, and delivering the packed and labelled products to major Western retailers’ shelves, with high service and quality requirements. The consistent and scalable execution of the supply chain can be attributed to the success of the company, however the rapid internationalisation process with several M&As, has implied challenges for maintaining execution capability.

The gherkins are a commodity product, with competitiveness based on low cost harvesting in India and consistent quality aligned with specifications. Retail packs (glass jars, cans, PET packages) are offered in sixteen different sizes, with several larger packaging sizes for food service and industrial purposes in barrels and cans. Powerful retail key accounts seek to impose customer specific variants in terms of packaging, adding to the supply chain complexity in terms of variants. There is also high level of variation in terms of key account behaviour. For example, UK based retailers may demand high volume commitments with short notice call-offs, French retailers may demand VMI arrangements while German discounters insist on predetermined delivery cycles, whereas, Eastern European wholesale and retail customers prefer to make opportunistic, low-margin, but from volume perspective quite significant consignment orders, implying high risk in terms of sales revenue. Generally, harmonisation of the international supply network configuration was difficult due to the heterogeneous demands of the powerful retailers, who enforce contracts with heavy penalties.

At the supply side in India, the company had built its success on effective crop management within the network of contract farmers, with high level of expertise embodied in key individuals. With the increase in the scale of business, and the general urbanisation trends in India, with large scale agricultural production moving further away from urban centres as a result, the relatively close physical proximity and sufficiency of the existing operational infrastructure required for effective cooperation between the supply base of farmers and the company experts, was lost, with detrimental effects on the crop management capability (e.g. seed and fertilizer specification, picking scheduling, crop yield and actual take-off estimation). In some cases, for example, crops grown with the company’s seeds were sold to competitors. Additionally, the expansion of the company, poor management and resultant personnel turnover, further diluted this key capability of managing the supply of seasonal, perishable, and highly specified products. It is evident that as a result of international expansion of sales and diminished supply management capability, a disconnect had formed between the front and the back ends of operations. Inexperienced sales staff was illiterate of the constraints of supply, and offered service and new product commitments that were essentially unmanageable at the supply side.

With this disconnect due to rapid growth, and the supply network complexity, resulting from a combination of internationally dispersed supply and production base (extra capacity due to legacy operations), seasonality (two per year) and perishability of supply (preserving produce in liquid prior to processing for longer periods would limit use in certain markets), difficulty in estimating crop yields, and a variety of order and contract types (with proliferation of general and key account specific product variant SKUs among the international customers), the operational matching of demand and supply became a challenging task. Consequently, a need for improved sales and operations planning (S&OP) capability was identified. Initially, an enterprise resource planning (ERP) module was imposed on the existing S&OP process, with failed implementation and no improvement in supply-demand matching. A renewed effort for improvement involved a more profound change approach. First, as growth through international M&As often implies management structures based on subsidiary and country representation, a new structure was implemented with functional representation at the board level and better alignment for coordinating the supply chain. The legacy operations footprint was redesigned, with several facility closures, and a new S&OP process, with an appropriate global organisation of some thirty specialists under a director of supply chain and a new supporting information system. The project for better alignment of international supply and demand lasted some eighteen months.

With the expansion of the international business and delivery contracts to major Western retailers, the expiry date and quality requirements, for example in terms of the tolerance for glass fragments in jars, became increasingly stringent for imports from India, seemingly exceeding the requirements for local supply for example in the case of the US market. In order to comply with these requirements, the company invested in new production technologies, such as automated processing machines and inline x-ray contaminant inspection equipment, as well as introduced new production control practices (at three sites in India). The cost of upgrading of processing capability cost several million USD and lasted three years, with doubts remaining whether the new capability level is sustainable. As a result of this, and the S&OP process redesign, several facilities in Hungary and India were also closed, and the company qualified for the requirements of the international market.

One of the key design decisions in terms of the international supply chain for gherkins was the location of processing and packing activities in the supply chain. The default alternative consisted of processing the produce in India and the other supply locations, transport in larger barrels to packing facilities located close to market, where final sales packaging and labelling took place. An intermediate design alternative suggested labelling in Belgium and sales packaging in Hungary, in order to avoid transit damage and achieve favourable country-of-origin status. The goal was, however, to finalise the main bulk of the product volume in terms of key account specific packaging and labelling already in India, in order to save on costs and to maintain quality, as less re-handling and re-packaging would take place in the later phases of the supply chain. Such early product customisation relied, however, on well-functioning S&OP process, and sales packaging that would withstand the strains of the international logistics pipeline. Initial design for the goal state resulted in quality problems in the form of damaged goods and sales packaging. As the outcome of a 15-month reconfiguration project, packaging and the underlying process were redesigned, with jar caps upgraded and transport packaging made sturdier, allowing the sales packaging and labelling activities to be finalised in India and the other supply markets, such as Hungary (covering for shortages in India), with a capability to meet quality and service requirements of the key account customers through the international logistics pipeline.

In conclusion, the board of the company initially comprised of country unit managers, combining international and local management perspectives. Supply network reconfiguration was predominantly in a reactive fire-fighting mode for several years during the internationalisation process, after which a change management project was initiated with brought-in external expertise. The overall result of the SN reconfiguration and adaptation, achieved through several projects, can be summarised as facility closures, lower fixed costs and better capacity utilisation, enhanced processes, as well as improved customer service.

Discussion of the pilot case

The case demonstrates a first attempt to utilise the proposed framework (Figure 1) and data collection instrument (Appendix A). The case product from India does not initially have a home market, however, as the company rapidly internationalises through M&As in order to acquire important customers and to acquire near-shore and back-up supply and production bases, the opportunity to optimise global operations imply replacement of local existing supply chains (e.g. in the US or Eastern Europe) with an international, mainly exports from India –based gherkin supply chain. The initial configuration is therefore mainly influenced by legacy and local experience based assumptions about home market, or in some cases, the host market without the international logistics pipeline. This M&A entry mode, and the initial regional supply network configuration, did not fit well with motivations to build on the home market CSA of low-cost harvesting and the FSA of crop management competence in India, making the initial, or M&A resultant SN configuration irrelevant for competing successfully in the business (Figure 1).

Therefore adaptation is needed, and as the case demonstrates, the SN configuration construct, and its operationalization through propositions that guide data collection, capture the adaptations quite well. In the case, we observe adaptation in all the SN construct's dimensions, as is discussed in the following (see also data display in Appendix B).

Supply network structure was adapted mainly in terms of the location of activities, in order to do as much as possible of the work involved at low cost in India, and therefore fully exploiting the CSA. However, in order for this to take place in a manner that enabled matching demand with supply, and within the requirements of the powerful retail customers, a way of coordinating key processes and reducing complexity had to be implemented in the form of redesigned S&OP process. Furthermore, the coordination was often extended outside the firm, as structures such as the VMI and different contracts were in some cases required. Therefore we see adaptation in both within unit processes and flows, as well as relationship governance. A further example of process adaptation was the effort to bring processing in line with the quality and safety requirements and standards, with compliance oriented investments into automation, inspection technology and new practices. Finally, adaptation in terms of product architecture was demonstrated in the form of product variants, often customer specific, as well as in the redesign of product and packaging characteristics for the demands of the international logistics pipeline.

In terms of matching the SN configurations to any of the adaptation patterns (Figure 1), we suggest the following (see also data display in Appendix B). Mimetic isomorphic mechanism for the initial configurations may have been in play through managers experience base and often perceived industry best practices (DiMaggio and Powell, 1983; Davis et al., 2000). However, the role of powerful retailers, and enforced regulation for imports, comes out much clearer in the case. It appeared that these coercive mechanisms, initiated by both downstream and regulator stakeholders (institutions), forced the case company to adapt the SN configuration, in order to comply with quality and safety standards. The initial reactive mode in reconfiguring the supply network is a tell-tale sign of attempts to operate home market convergent configurations initially, however, with divergence kicking in as the host market and logistics pipeline requirements make the initial configuration unsustainable (divergence is the main form of adaptation). Interestingly, the adaptation in terms of processes spans both home and host markets, whereas, in a typical AM to EM case, home market processes, being in a competitive situation benchmarked and efficient, would perhaps not be so saliently affected, as was the case in the pilot investigation.

Based on our single observation, the cycle pattern suggested by Lorentz et al. (2013) specifically for the AM to EM context, may not be completed to convergence in the EM to AM context. Furthermore, aligned with the pattern suggested by Lessard and Lucea (2009), the case company tried to exploit its CSA based FSA, however, it had to enhance its capabilities, and is now in the position to exploit the reconfigured SN and the resulting FSA (now relying on the CSA of India, but newly developed capabilities such as the enhanced S&OP) in both the AM and the EM markets, as well as in the emerging home market fast-food and supermarket supply chains. As the cross-case data display shows (Appendix C), most of the supply network adaptation is of the enhancement type, concerned with the areas of company processes and flows, and most saliently driven by institutions and downstream actors (retailers).

Conclusions

This paper has suggested a framework for the investigation of how emerging market food firms adapt their supply networks in the context of internationalisation to advanced markets, and contrasting this with the opposite case in terms of the direction of internationalisation. The framework draws on the theories of internalisation and organisational change due to isomorphic mechanisms, and builds on the previous work by Lorentz et al. (2013).

By operationalizing the framework, the paper suggests a process and tools for collecting and analysing data and drawing conclusions on the nature and patterns of SN adaptation in the EM to AM context. The framework and the data collection and analysis tools were tested by the means of a pilot case study on an integrated Indian food company, with a global operations footprint and sales. The results of the case study suggest the relevance of the research approach and the tools, as SN configuration adaptation was observed in all the major dimensions of the key construct (Srai and Gregory, 2008), and relevant results drawn from the case.

Further research should employ a multiple case study approach by collecting a dataset with cases from a variety of emerging markets, preferably including the BRICs, as well as on a variety of food products, including commodities and differentiated products, as well as perishable and non-perishable. An international research team is proposed as the appropriate organisation for the data collection, with local knowledge of each market, and with a case study protocol guiding case selection and the employed field practices. The larger data set would allow the identification of adaptation patterns and a degree of increased generalizability. The results would contribute to the internationalisation theory from supply chain management and operations perspectives, as well as inform theoretical and practical knowledge on international supply network design and planning strategic responses to international competition.

References

Ahumada, O. and Villalobos, J.R. (2009). Application of planning models in the agri-food supply chain: A review, *European Journal of Operational Research*, 195/1, 1-20.

Ailawadi, K.L. (2001). The retail power-performance conundrum: What have we learned?, *Journal of Retailing*, 77/3, 299-318.
Amit, R. and Schoemaker, P.J.H. (1993). Strategic assets and organizational rent, *Strategic Management Journal*, 14/1, 33-46.
Anderson, J.C., Håkansson, H. and Johanson, J. (1994). Dyadic Business Relationships Within a Business Network Context. *Journal of Marketing*, 58/4, 1-15.
Arvis, J.-F., Mustra, M. A., Ojala, L., Shepherd, B. and Saslavsky, D. (2012). *Connecting to Compete 2012 – Trade Logistics in the Global Economy*, World Bank, available at: http://www.worldbank.org/lpi (accessed 21 June 2013).
Banalieva, E.R. and Sarathy, R. (2010). The Impact of Regional Trade Agreements on the Global Orientatioin of Emerging Market Multinationals, *Management International Review*, 50/6, 797-826.
Barrett, H.R., Ilbery, B.W, Browne, A.W. and Binns, T. (1999). Globalization and the Chnaging Networks of Food Supply: The Importation of Fresh Horticultural Produce from Kenya into the UK, *Transactions of the Institute of British Geographers*, 24/2, 159-174.
Blandon, J., Henson, S. and Cranfield, J. (2009). Small-scale farmer participation in new agri-food supply chains: case of the supermarket supply chain for fruit and vegetables in Honduras, *Journal of International Development*, 21/7, 971-984.
Boselie, D., Henson, S. and Weatherspoon, D. (2003). Supermarket Procurement Practices in Developing Countries: Redefining the Roles of the Public and Private Sectors, *American Journal of Agricultural Economics*, 85/5, 1155-1161.
Bozarth, C.C., Warsing, D.P., Flynn, B.B., and Flynn, E.J. (2009). The impact of supply chain complexity on manufacturing plant performance, *Journal of Operations Management*, 27/1, 78-93.
Brookes, R. (1995). Recent Changes in the Retailing of Fresh Produce: Strategic Implications for Fresh Produce Suppliers, *Journal of Business Research*, 32/2, 149-161.
Buhr, B.L. (2003). Traceability and Information Technology in the Meat Supply Chain: Implications for Firm Organisation and Market Structure, *Journal of Food Distribution Research*, 34/3, 13-26.
Cadilhon, J.-J., Moustier, P., Poole, N. D., Tam, P. T. G. and Fearne, A. (2006). Traditional vs. Modern Food Systems? Insights from Vegetable Supply Chains to Ho Chi Minh City (Vietnam), *Development Policy Review*, 24/1, 31-49.
Christensen, C.M. (2006). The Ongoing Process of Building Theory of Disruption. *Journal of Product Innovation Management*, 23/1, 39-55.
Christou, I.T. and Ponis, S. (2008). Enhancing traditional ATP functionality in open source ERP systems: A case study from the food & beverages industry, *International Journal of Enterprise Information Systems*, 4(1), 18-33
Coe, N.M. and Hess, M. (2005). The internationalization of retailing: implications for supply network restructuring in East Asia and Eastern Europe, *Journal of Economic Geography*, 5/4, 449-473.
Corsten, D. and Kumar, N. (2005). Do Suppliers Benefit from Collaborative Relationships with Large Retailers? An Empirical Investigation of Efficient Consumer Response Adoption, *Journal of Marketing*, 69/3, 80-94.
Cuervo-Cazurra, A. (2013). How emerging market multinational enterprises upgrade capabilities using value-chain configuration in advanced economies, in: *The Competitive Advantage of Emerging Market Multinationals*, ed. by P.J. Williamson, R. Ramamurti, A. Fleury and M.T.L. Fleury, Cambridge University Press, Cambridge.
Davis, P.S., Desai, A.B. and Francis, J.D. (2000). Mode of International Entry: An Isomorphism Perspective, *Journal of International Business Studies*, 31/2, 239-258.

DiMaggio, P.J. and Powell, W.W (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields, *American Sociological Review*, 48/2, 147-160.
Dobson, P.W., Waterson, M. and Davies, S.W. (2003). The Patterns and Implications of Increasing Concentration in European Food Retailing, *Journal of Agricultural Economics*, 54/1, 111-125.
Dolan, C. and Humprey, J. (2000). Governance and Trade in Fresh Vegetables: The Impact of UK Supermarkets on the African Horticulture Industry, *The Journal of Development Studies*, 37/2, 147-176.
Duffy, R. and Fearne, A. (2004). The Impact of Supply Chain Partnerships on Supplier Performance, *International Journal of Logistics Management*, 15/1, 57-72.
Eisenhardt, K. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, 14/4, 532-550.
Engelseth, P. (2009). Food product traceability and supply network integration, *Journal of Business & Industrial Marketing*, 24/5/6, 421-430.
Fawcett, S.E., Calantone, R. and Smith, S.R. (1997). Delivery capability and firm performance in international operations. *International Journal of Production Economics*, 51/3, 191-204.
Gorton, M., Dumitrashko, M. and White, J. (2006). Overconing supply chain failure in the agri-food sector: A case study from Moldova, *Food Policy*, 31/1, 90-103.
Gulyani, S. (2001). Effects of Poor Transportation on Lean Production and Industrial Clustering: Evidence from the Indian Auto Industry. *World Development*, 29/7, 1157-1177.
Gunasekaran, A., Patel, C. and Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment, *International Journal of Operations & Production Management*, 21/1/2, 71-87.
Halinen, A. and Törnroos, J.-Å. (2005). Using case methods in the study of contemporary business networks, *Journal of Business Research*, 58/9, 1285-1297.
Handfield, R.B. and Withers, B. (1993). A Comparison of Logistics Management in Hungary, China, Korea and Japan, *Journal of Business Logistics*, 14/1, 81-109.
Helfat, C.E. and Peteraf, M.A. (2003). The dynamic resource-based view: capability lifecycles, *Strategic Management Journals*, 24/10, 997-1010.
Henson, S. and Humphrey, J. (2010). Understanding the Complexities of Private Standards in Global Agri-Food Chains as They Impact Developing Countries, *The Journal of Development Studies*, 46/9, 1628-1646.
Henson, S. and Jaffee, S. (2008). Understanding Developing Country Strategic Responses to the Enhancement of Food Safety Standards, *The World Economy*, 31/4, 548-568.
Henson, S., Masakure, O. and Boselie, D. (2005). Private food safety and quality standards for fresh produce exporters: The case of Hortico Agrisystems, Zimbabwe, *Food Policy*, 30/4, 371-384.
Hobbs, J.E. and Young, L.M. (2000). Closer vertical co-ordination in agri-food supply chains: a conceptual framework and some preliminary evidence, *Supply Chain Management: An International Journal*, 5/3, 131-143.
Holweg, M., Disney, S., Holmström, J. and Småros, J. (2005). Supply Chain Collaboration: Making Sense of the Strategy Continuum, *European Management Journal*, 23/2, 170-181.
Hsiao, H.I., Kemp, R.G.M., van der Vorst, J.G.A.J and Omta, S.W.F. (2010). A classification of logistic outsourcing levels and their impact on service performance: Evidence from the food processing industry, *International Journal of Production Economics*, 124/1, 75-86.

Humphrey, J. (2007). The supermarket revolution in developing countries: tidal wave or tough competitive struggle?, *Journal of Economic Geography*, 7/4, 433-450.
Humphrey, J. and Schmitz, H. (2002). How Does Insertion in Global Value Chains Affect Upgrading in Industrial Clusters?, *Regional Studies*, 36/9, 1017-1027.
Jarratt, D. (2004). Conceptualizing a relationship management capability, *Marketing Theory*, 4/4, 287-309.
Jiang, B. (2002). How international firms are coping with supply chain issues in China. *Supply Chain Management: An International Journal*, 7/4, 184-188.
Johnson, J.P., Lenartowicz, T. and Apud, S. (2006). Source Cross-Cultural Competence in International Business: Toward a Definition and a Model, *Journal of International Business Studies*, 37/4, 525-543.
Kaynak, E. and Cavusgil, S.T. (1982). The Evolution of Food Retailing Systems: Contrasting the Experience of Developed and Developing Countries, *Journal of the Academy of Marketing Science*, 10/3, 249-269.
Kelepouris, T., Pramatari, K. and Doukidis, G. (2007). RFID-enabled traceability in the food supply chain, *Industrial Management & Data Systems*, 107/2, 183-200.
Kittipanya-ngam, P., Shi, Y. and Gregory, M.J. (2011). Exploring geographical dispersion in Thailand-based food supply chain (FSC), *Benchmarking: An International Journal*, 18/6, 802-833.
Klossek, A., Linke, B.M. and Nippa, M. (2012). Chinese enterprises in Germany: Establishment modes and strategies to mitigate the liability of foreigness, *Journal of World Business*, 47/1, 35-44.
Lee, H. (2004). The Triple-A Supply Chain. *Harvard Business Review*, October.
Lessard,D.R and Lucea, R. (2009). Mexican multinationals: Insights from CEMEX, in: *Emerging Multinationals in Emerging Markets*", ed. by R. Ramamurti and J.V. Singh, Cambridge University Press, Cambridge.
Liao, K., Marsillac, E., Johnson, E. and Liao, Y. (2011). Global supply chain adaptations to imporve financial performance. *Journal of Manufacturing Technology Management*, 22/2, 204-222.
Lorentz, H. and Ghauri, P.N. (2010). Demand supply network opportunity development processes in emerging markets: positioning for strategy realization in Russia. *Industrial Marketing Management*, 39/2, 240-251.
Lorentz, H., Kittipanya-ngam, P. and Srai, J.S. (2013). Emerging market characteristics and supply network adjustments in internationalising food supply chains, *International Journal of Production Economics*, 145/1, 220-232.
Lorentz, H., Wong, C.Y. and Hilmola, O.-P. (2007). Emerging distribution systems in Central and Eastern Europe: Implications from two case studies. *International Journal of Physical Distribution & Logistics Management*, 37/8, 670-697.
Mahalik, N.P. and Nambiar, A.N. (2010). Trends in food packaging and manufacturing systems and technology, *Trends in Food Science & Technology*, 21/3, 117-128.
Matopoulos, A., Vlachopoulou, M. and Manthou, V. (2007). A conceptual framework for supply chain collaboration: empirical evidence from the agri-food industry, *Supply Chain Management: An International Journal*, 12/3, 177-186.
McAfee, R.B., Glassman, M. and Honeycutt, E.D. (2011). The effects of culture and human resource management policies on supply chain management strategy, *Journal of Business Logistics*, 23/1, 1-18.
Mergenthaler, M., Weinberger, K. and Qaim, M. (2009). The food system transformation in developing countries: A disaggregate demand analysis for fruits and vegetables in Vietnam, *Food Policy*, 34/5, 426-436.

Miles, M.B. and Huberman, A.M. (1994). *Qualitative Data Analysis – An Expanded Sourcebook*, second ed., Sage publications, Thousand Oaks.
Muradian, R. and Pelupessy, W. (2005). Governing the Coffee Chain: The Role of Voluntary Regulatory Systems, *World Development*, 33/12, 2029-2044
Nassimbeni, G. and Sartor, M. (2007). Sourcing in China: a typology. *International Journal of Production Economics*, 107/2, 333-349.
North, D.C. (1990). *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press.
Patton, M.Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage Publications.
Prasad, S., Tata, J. and Madan, M. (2005). Build to order supply chains in developed and developing countries. *Journal of Operations Management*, 23/5, 551-568.
Ramamurti, R. (2009). Why study emerging-market multinationals?, in: *Emerging Multinationals in Emerging Markets*, ed. by R. Ramamurti and J.V. Singh, Cambridge University Press, Cambridge.
Reardon, T., Timmer, C.P., Barrett, C.B. and Berdegué, J. (2003). The Rise of Supermarkets in Africa, Asia, and Latin America, *American Journal of Agricultural Economics*, 85/5, 1140-1146.
Renting, H., Marsden, T.K. and Banks, J. (2003). Understanding alternative food networks: exploring the role of short food supply chains in rural development, *Environment and Planning*, 35/3, 393-411.
Réviron, S. and Chappuis, J.-M. (2005). Effects of the Swiss Retailers' Strategy on the Governance Structure of the Fresh Food Products Supply Chains, *Agribusiness*, 21/2, 237-252.
Richey, R.G., Tokman, M. and Skinner, L.R. (2008). Exploring collaborative technology utilization in retailer–supplier performance, *Journal of Business Research*, 61/8, 842-849.
Roth, A.V., Tsay, A.A., Pullman, M.E. and Gray, J.V. (2008). Unravelling the food supply chain: strategic insights from China and the 2007 recalls, *Journal of Supply Chain Management*, 44/1, 22-39.
Rugman, A.M. (1981). *Inside the Multinationals: The Economics of Internal Markets*. New York: Columbia University Press.
Salin, V. and Nayga, R.M. (2003). A cold chain network for food exports to developing countries, International Journal of Physical Distribution & Logistics Management, 33/9/10, 918-933.
Skjoett-Larsen, T., Thernøe, C. and Andresen, C. (2003). Supply chain collaboration: Theoretical perspectives and empirical evidence, *International Journal of Physical Distribution & Logistics Management*, 33/6, 531-549.
Solakivi, T., Töyli, J., Engblom, J. and Ojala, L. (2011). Logistics outsourcing and company performance of SMEs: Evidence from 223 firms operating in Finland, *Strategic Outsourcing: An International Journal*, 4/2, 131-151.
Spencer, M.S. (2000). Theory of constrains in a service application: the swine graphics case, *International Journal of Production Research*, 38/5, 1101-1108.
Srai, J.S. (2013). Value-chain configurations of emerging country multinationals, in: *The Competitive Advantage of Emerging Market Multinationals*", ed. by P.J. Williamson, R. Ramamurti, A. Fleury and M.T.L. Fleury, Cambridge University Press, Cambridge.
Srai, J.S. and Alinaghian, L.S. (2013). Value chain reconfiguration in highly disaggregated industrial systems: examining the emergence of health care diagnostics, *Global Strategy Journal*, 3/1, 88-108.

Srai, J.S. and Gregory, M. (2008). A supply network configuration perspective on international supply chain development. *International Journal of Operations & Production Management*, 28/5, 386-411

Srai, J.S. and Gregory, M.J. (2005). Supply chain capability assessment of global operations, *Proceedings of Euroma 2005*, Budapest.

Swamidass, P.M. and Newell, W.T. (1987). Manufacturing Strategy, Environmental Uncertainty and Performance: A Path Analytic Model. *Management Science*, 33/4, 509-524.

Swinnen, J.F.M. and Maertens, M. (2007). Globalization, privatization, and vertical coordination in food value chains in developing and transition countries, *Agricultural Economics*, 37/ s1, 89-102.

Taylor, D.H. (2005). Value-chain analysis: an approach to supply chain improvement in agri-food chains, *International Journal of Physical Distribution & Logistics Management*, 35/9/10, 744-761.

Teece, D.J., Pisano, G. and Shuen, A. (1997). Dynamic capabilities and strategic management, *Strategic Management Journal*, 18/7, 509-533.

Trienekens, J. and Zuurbier, P. (2008). Quality and safety standards in the food industry, developments and challenges, *International Journal of Production Economics*, 113/1, 107-122.

Ulrich, K. (1995). The role of product architecture in the manufacturing firm, Research Policy, 24/3, 439

UNCTAD (2012). *World Investment Report 2012 - Towards a New Generation of Investment Policies*. http://unctad.org/en/ (accessed 21.6.2013)

van der Vorst, J.G.A.J., Beulens, A.J.M., de Wit, W. and van Beek, P. (1998). Supply Chain Management in Food Chains: Improving Performance by Reducing Uncertainty, *International Transactions in Operational Research*, 5/6, 487-499.

van Hoek, R.I. (1999). Postponement and the reconfiguration challenge for food supply chains, *Supply Chain Management: An International Journal*, 4/1, 18-34.

Waller, M.A., Johnson, E.M. and Davis, T. (1999). Vendor-managed inventory in the retail supply chain, *Journal of Business Logistics*, 20/1, 183-203

Wang, K. and Shi, Y. (2013). Value-chain configurations of Chinese EMNEs, in: *The Competitive Advantage of Emerging Market Multinationals*, ed. by P.J. Williamson, R. Ramamurti, A. Fleury and M.T.L. Fleury, Cambridge University Press, Cambridge.

Ward, P.T., Duray, R., Leong, G.K. and Sum, C.-C. (1995). Business environment, operations strategy, and performance: An empirical study of Singapore manufacturers, *Journal of Operations Management*, 13/2, 99-115.

Watts, D.C.H, Ilbery, B. and Maye, D. (2005). Making reconnections in agro-food geography: alternative systems of food provision, *Progress in Human Geography*, 29/1, 22-40.

Weatherspoon, D.D. and Reardon, T. (2003). The Rise of Supermarkets in Africa: Implications for Agrifood Systems and the Rural Poor, *Development Policy Review*, 21/3, 333-355.

Wells, L.T. (2009). Third World Multinationals: A Look Back, in: *Emerging Multinationals in Emerging Markets*, ed. by R. Ramamurti and J.V. Singh, Cambridge University Press, Cambridge.

Wilding, R. and Juriado, R. (2004). Customer perceptions on logistics outsourcing in the European consumer goods industry, *International Journal of Physical Distribution & Logistics Management*, 34/8, 628- 644.

Williamson, O.E. (1973). Markets and Hierarchies: Some Elementary Considerations, *The American Economic Review*, 63/2, 316-325.

WTO (2011). *World Trade Report 2011 - The WTO and preferential trade agreements: From co-existence to coherence*. http://www.wto.org/english/ (accessed 21.6.2013).
Yin, R.K. (2003). *Case Study Research*, third ed., Thousand Oaks: Sage Publications.
Ziggers, G.W. and Trienekens, J. (1999). Quality assurance in food and agribusiness supply chains: Developing successful partnerships, *International Journal of Production Economics*, 60-61/1, 271-279.

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Appendix A Data display for within-case analyses, with interview guideline incorporated

<u>The aim of the interview:</u> to understand the evolution of the product's supply chain during the internationalization process and product life-cycle.

SN config. dimensions	***Network structure***			***Processes and flows***				***Relationship governance***		***Product architecture***			
Cases	*Tier structure (breadth and length)*	*Firm boundaries (in house vs. outsourcing)*	*Value chain configuration (location)*	*Processing technology (manual, automation)*	*Standard compliance (quality, safety, sustainable)*	*Replenishment mode (location of DCP)*	*Order fulfilment and logistics process (incl. S&OP)*	*Relationship types (contracts, partnerships, trust), and breadth.*	*Areas of coordination (Integ. S&OP, VMI, logistics, product attributes)*	*Product variants and offering (service component)*	*Product life-cycle (incl. innovation churn)*	*Product mobility (value-density, packaging)*	*Other area(s) of adaptation*
Product A; Firm A 1. Motives and process of internat-ionalisation? 2. Was the product originally designed for EM or AM? 3. Please describe market positioning of the product, e.g. commodity or differentiated 4. What are the order winning factors for the product? 5. Please, briefly describe your background, as well as of those involved in designing the international supply chain in the past.	6. a) Please describe the participants in the product's host market supply chain. *(e.g. tiers, middlemen, exclusivity)*	7. a) Please describe the major supply chain activities that have been outsourced to third parties in the product's host market supply chain.	8. a) Please describe the product's supply chain phases by location, typical for the host market.	9. a) Please describe the key processing technologies in use in the product's host market supply chain. *Any significant investments ?*	10. a) Please describe the requirements for standard compliance in the product's host market supply chain.	11. a) Please describe the predominant replenishment mode (MTO, MTS etc.) used in the product's host market supply chain.	12. a) Please describe the key features and requirements for product's order fulfilment and logistics processes for the host market. *(e.g. availability, timeliness, inventory holding)*	13. a) Please describe the nature of business relationships and the interfaces (bowtie vs. diamond) between the key external actors in the product's host market supply chain.	14. a) Please describe the main areas of cooperation and information exchange with the key external actors in the product's host market supply chain.	15. a) Please describe number of product variants and nature of product/service offering in the host market supply chain. *Service components?* *Any key account specificity?*	16. a) Please describe the variant life-cycle and rate of introductions in the product's host market supply chain.	17. a) Please describe the nature of key product/ packaging attributes e.g. for transport in the product's host market supply chain.	18. a) Any other areas with supply chain changes or with difference to home market during the product's internationa lisation process?
	6.-17. b) What CHANGES, if any, have occurred in this respect during the product's internationalisation process? WHY? (drivers)												
	6.-17. c) If no change has taken place, how is the situation DIFFERENT in the HOME market for the same or similar product? WHY? (drivers)												
	6.-17. d), or 18. b) HOW did the change or difference come about? (timeline and process, cost and resource deployment)												
	6.-17. e), or 18. c) What were the IMPLICATIONS of the changes or differences in terms of PERFORMANCE (customer service and satisfaction, delivery, manufacturing, sourcing, planning) and supply chain CAPABILITY (in terms of the order winning factors)?												

Appendix B Data display for within-case analyses, with pilot case data incorporated

SN config. dimensions	***Network structure***			***Processes and flows***				***Relationship governance***		***Product architecture***		
Cases	*Tier structure (breadth and length)*	*Firm boundaries (in house vs. outsourcing)*	*Value chain configuration (location)*	*Processing technology (manual, automation)*	*Standard compliance (quality, safety, sustainable)*	*Replenish ment mode (location of DCP)*	*Order fulfilment and logistics process (incl. S&OP)*	*Relationship types (contracts, partnerships, trust), and breadth.*	*Areas of coordination (Integ. S&OP, VMI, logistics, product attributes)*	*Product variants and offering (service component)*	*Product life-cycle (incl. innovation churn)*	*Product mobility (value-density, packaging)*
Exported gherkins from India to Europe & North America; *Firm A* 1. Motive and process: international sales growth and capacity through M&A 2. Product originally designed for EM 3. Market position: commodity 4. OWF: low cost 5. Backgrounds, international chairman of BoD, local country unit managers, international independent consultant brought in the later phase of reconfig.	6. a) 1000s of contract farmers → focal firm processing → focal firm and partners packaging → large retailer key accounts	7. a) na	8. a) Product harvested, processed, packed and labelled in India, key back-up locations in Eastern Europe, delivery to Western Europe, North America and Far East.	9. a) Automated processing and packaging, in-line x-ray inspection	10. a) Meets stringent quality requirements from retail key accounts and in terms of import regulations, e.g. by using in-line x-ray inspection	11. a) MTS.	12. a) Meets tight delivery windows, appropriate S&OP process in place that matches demand and supply of multiple SKUs and in terms of several supply and demand locations.	13. a) Several types of contracts in Europe: e.g. high volume commitments with two-week call-offs, consignment orders.	14. a) VMI, discussion of product attributes, predetermined delivery cycles to retail key accounts, close crop management cooperation with farmers	15. a) Several SKU variants due to packaging size, key account specific variants.	16. a) na	17. a) Packaging meets the demands of the export logistics pipeline and customers.
	6. b) na	7. b) na	8. b) As a result of M&As: part of harvesting, and most packaging and labelling done in host market. Several legacy processing facilities. Change towards all value-added in India, with back-up locations in Europe → facility closures. (R→ENHANCE)	9. b) Legacy equipment, manual process in India. Upgrade due to compliance pressure. Improved production processes implemented. (I&DS→ COERCIVE, DIVERGENT, ENHANCE)	10. b) Quality compliance had to be improved (e.g. % of glass shards in jars) → inspection technology and practice upgrade (see 9. b)	11. b) na	12. b) Planning complexity required replenishment from nearby, change required the support from a redesigned S&OP, with appropriate IS and organisation. (R&DS→ ENHANCE)	13. b) na	14. b) Towards more coordination with retailers, crop management competence diluted during growth → improved (DS→ COERCIVE, ENHANCE; US→ ENHANCE)	15. b) na	16. b) na	17. b) Packaging did not meet the demands of international logistics → quality problems→ sturdier material and rust-proof caps, key account specific changes (G→COERCIV E, ENHANCE)
	6. d) na	7. d) na	8. d) 18 month project	9. d) cost several million USD, during three years,	10. d) see 9. d)	11. d) na	12. d) 18 month project	13. d) na	14. d) na	15. d) na	16. d) na	17. d) 15 month project
	6. e) na	7. e) na	8. e) Reduced fixed costs, improved capacity utilisation, delivery and customer service.	9. e) Improved processing performance, doubts whether sustainable.	10. e) Improved delivery performance and customer satisfaction, OQF	11. e) na	12. e) Improved delivery performance, ability to draw on the CSA of India (main supply location at low cost). OWF	13. e) na	14. e) deliver and supply performance improved, OQF	15. e) na	16. e) na	17. e) improved delivery performance, OQF

Notes: OQF=order qualifying factor, OWF=order winning factor; DCP=decoupling point, S&OP=sales and operation planning, VMI=vendor managed inventory;
In cells X b), the following symbols indicate the drivers for adaptation (see Figure1): G=geography (e.g. long distance), R=resources (e.g. low-cost labour and transport infrastructure), I=institutions (import regulations), DS=downstream actor (e.g. retailer), US=upstream actor (e.g. farmer), Sup=supporting actor (e.g. logistics service provider). CAPITAL letters indicate authors' matches to adaptation patterns (Figure 1).

Appendix C Data display for cross-case analysis, with pilot case data incorporated

Adaptation type	**Network structure**			**Processes and flows**				**Relationship governance**		**Product architecture**			**TOTAL**
	Tier structure	Firm boundaries	VC configuration	Process. technology	Standard compliance	Replenish. mode	Order fulfil. & logistics	Relationship types	Areas of coordination	Product variants	PLC	Product mobility	
Geography												Coer: 1 Enh: 1	Mim: Coer: Norm: Div: Conv: Exp: Enh:
Resources			Enh: 1				Enh: 1						Mim: Coer: Norm: Div: Conv: Exp: Enh:
Institutions				Coer: 1 Div: 1 Enh: 1	Coer: 1 Div: 1 Enh: 1								Mim: Coer: Norm: Div: Conv: Exp: Enh:
Upstream									Enh: 1				Mim: Coer: Norm: Div: Conv: Exp: Enh:
Downstream				Coer: 1 Div: 1 Enh: 1	Coer: 1 Div: 1 Enh: 1		Enh: 1		Coer: 1 Enh: 1				Mim: Coer: Norm: Div: Conv: Exp: Enh:
Supportive													Mim: Coer: Norm: Div: Conv: Exp: Enh:
TOTAL	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	Mim: Coer:	**Mim:** **Coer:**

	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	Norm: Div: Conv: Exp: Enh:	**Norm:** **Div:** **Conv:** **Exp:** **Enh:**

An Analytical Framework for Emerging Country Multinationals' International Operations Management

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Abstract

International Operations Management (IOM) focuses on multinationals from advanced countries mainly. In doing so, IOM leaves aside important issues which are relevant components of its backbone. In the case of emerging multinationals from emerging countries (EMECs), these have had to rapidly evolve their manufacturing systems, from national, stand-alone factories, to global, corporate networks of factories. However, the approaches developed by IOM theories have limited resources to address the challenges faced by firms initiating their internationalization processes. In this article, a multi-level, network-based analytical framework is devised, having the EMEC's network of subsidiaries as focal concern. This framework was developed for case study approach in a comparative analysis of Brazilian and Chinese multinationals; it illustrated by using cases available in the business management literature.

Keywords
Internationalization, international operations management, emerging country multinationals, manufacturing networks.

1 INTRODUCTION

As latecomers in international markets, emerging firms from emerging countries (EMEC) have had to rapidly change their manufacturing system concepts, from a focus on national, stand-alone factories towards a global, corporate network of factories. This opens the possibility of new research streams looking at international manufacturing network systems in terms of structural architecture, dynamic mechanisms, and related strategic capabilities and processes (Shi and Gregory, 1998).

The expansion of EMECs was unpredicted, because they have been usually seen as mature and vertically integrated firms which grew in home markets protected from international competition (Ramamurti, 2009).Thus, they would not possess the advanced technological and managerial competences needed to create ownership advantages to explore abroad (Li and Rugman, 2007). Nonetheless, they are expanding internationally and their Production competences play a key role in that process (Fleury and Fleury, 2011).

The way in which international operations are managed is still poorly understood in the cases of developed country multinationals: "despite the importance attached to it by both academics and practitioners, the field of International Operations Management (IOM) is still at a relatively early stage of theory development" (Vereecke and van Dierdonck, 2002). More recently, some IOM branches became hot issues: global value chain management, international sourcing and procurement, supply chain management (Holweg et al., 2011; Contractor et al., 2010). However, a more integrative approach to IOM is still missing (Shi and Gregory, 2003). That gap is still bigger when it comes to EMECs (Grossler, Laugen, Arkader and Fleury, 2013).

Internationalization studies on EMECs, from an IOM perspective, have specific characteristics because:

1) EMECs go abroad with the support of Firm-Specific Advantages (FSAs) different from FSAs displayed by advanced country multinationals (Zeng and Williamson, 2008; Ramamurti, 2009; Fleury, Fleury and Borini, 2010); in particular, EMECs rely on Production as their key competence for internationalization (Fleury and Fleury, 2011), while advanced country multinationals internationalize based on Product and Marketing competences mainly;
2) EMECs' internationalization process is fast-paced, which is crucial for their catch-up strategies (Mathews, 2006);
3) EMECs' internal networks of subsidiaries are critical for accelerating their learning process, a condition for the increase of their overall competitiveness (Williamson et al., 2013).

Therefore, it is expected that the management of international operations by EMECs display specific features. The key questions to be addressed in studies about EMECs' internationalization are: How do EMECs conduct IOM? Are they developing new IOM models? What contributions the studies on EMECs' internationalization may bring to IOM theory?

However, prior to the development of theory, it is necessary to establish appropriate analytical frameworks. There are multiple dimensions to be addressed in studies on EMECs' IOM. First, the internationalization of emerging country firms is influenced by institutional factors, a reason for Peng et al. (2008) to suggest the application of the *tripod approach*, a combination of the resource-based approach, the industry-analysis approach and the institution-based approach. Second, internationalization may occur under the influence of Global Production Networks (GPN), meaning that the decision to go abroad depends on the role the EMEC performs in global networks led by advanced country firms. Third, the fact that EMECs are infant multinationals means that the existing frameworks, developed for mature multinationals dealing with legacy networks may not be adequate for approaching the phenomenon.

In this paper, a framework for the study of EMECs' IOM is developed, seeking to incorporate the specifics aforementioned. To achieve that aim, the overall structure of the framework is built based on both the IOM and the International Business literature. Next, a review of analytical frameworks already published on international manufacturing and engineering networks, leads to the identification of three basic approaches to be used in the structuring of the new framework. In the following section, the multi-level framework, the key constructs and variables are presented. Then, the analytical model is built, by incorporating previous insights present in the literature. Some illustrative examples follow, extracted from the business management literature, and the article concludes with the next steps for the conduction of the upcoming fieldwork.

2 BUILDING THE INTEGRATIVE FRAMEWORK

Three perspectives currently rule the analyses of IOM within multinational companies: 1) the multinational as a network of competences; 2) the multinational as a network of subsidiaries; and 3) the multinational as part of GPNs. A schematic representation of the multinational, composed by three networks is shown in Fig. 1:

Level 1: Each subsidiary of the multinational organizes its own networks, bundling internal competences and external resources: this level can be approached by frameworks that analyze the relationship between the subsidiary's various internal sites (production plants, R&D centers, distribution centers, etc.) and its external trading partners (3^{rd} party contractors, suppliers, logistics providers, distributors, clients, etc.), either within the subsidiary's host country or in other (neighboring) countries. A common analytical framework for it is the Supply Chain Management (Shafer and Meredith, 1998).

Level 2: It is the focus of this research; it refers to the internal (intra-firm) network of parent company (headquarters) and affiliate companies (subsidiaries): this level can be approached by frameworks that analyze the relationship between the multinational's parent company and its affiliates (Bartlett and Ghoshal, 1998; Rugman and Verbeke, 2001), as well as the roles of the affiliates (Rugman, Verbeke, Yuan, 2010) and the ones that concentrate on specific functions (Shi and Gregory, 1998; Zhang and Gregory, 2011);

Level 3: The multinational is part of a GPN: this level can be approached by the Competence-Based Positioning Framework (Gereffi, Humphrey and Sturgeon, 2005; Fleury and Fleury, 2007).

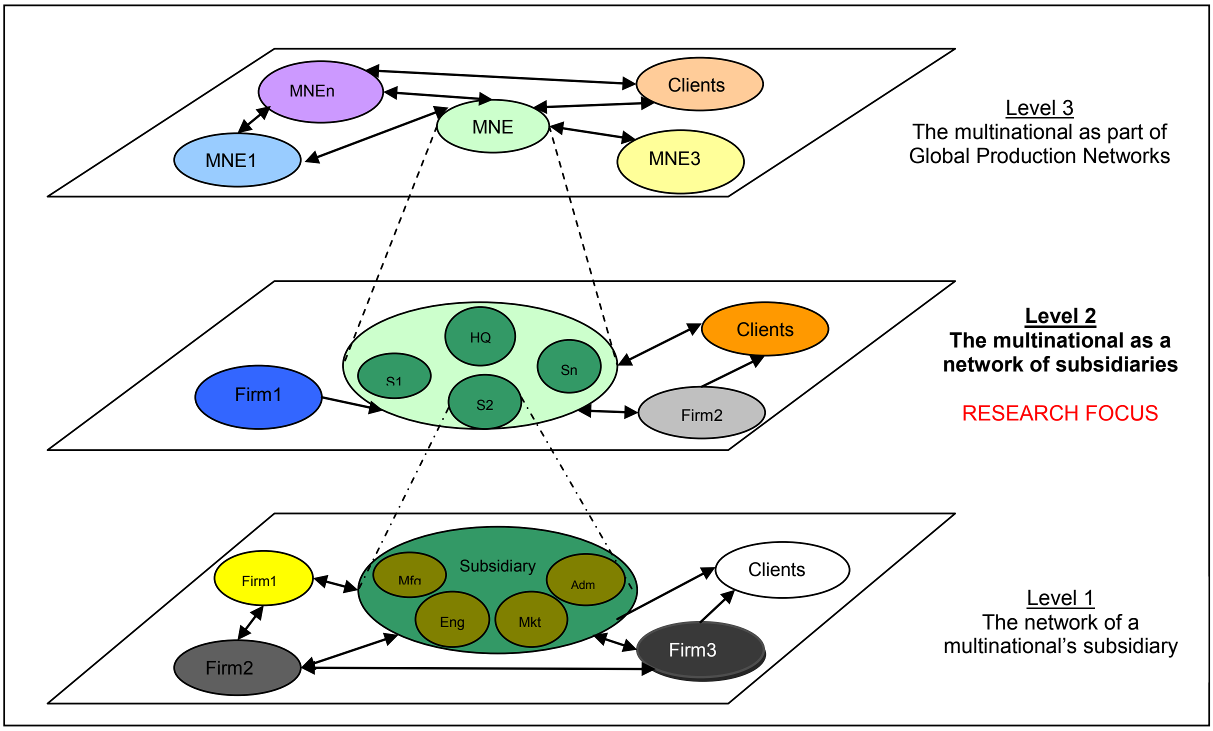

Fig. 1 – A multinational company's industrial and internal organization: three levels of networks. The authors.

2.1 The analytical framework and its key elements

For the building of the framework, three partial theoretical approaches were considered: GMN - Global Manufacturing Networks (Fleet and Shi, 2005), GEN - Global Engineering Networks (Zhang, Gregory and Shi, 2008), and CbPF - Competence-based Positioning Framework (Fleury and Fleury, 2007).

The key elements for the analysis of networks, common to all three theoretical approaches above mentioned, are: (a) Design and Structure, (b) Governance and Coordination and (c) Processes and Infrastructure, (Table 1).

Tab. 1 – Key elements for network-based operations

Element	Global Manufacturing Networks (Shi and Gregory, 1998) Level 2	Global Engineering Networks (Zhang and Gregory, 2011) Level 2	Competence Positioning (Fleury and Fleury, 2007) Level 3
Design and structure	Consider individual plant's characteristics and the degree of geographic dispersion	Critical aspects include: geographic dispersion, resources and roles of engineering centers, and rationales for network structure design	Assume that the position of each firm within the global production network is related to its competence profile
Governance and coordination	Include horizontal/vertical coordination, dynamic capability building and network evolution	Include the authority structure and the performance measures	Governance is exerted by the firm which possesses the most strategic competences and capabilities for the GPN's performance
Processes and infrastructure	Include operational mechanisms, dynamic response mechanisms, PLM and knowledge transfer processes	Describe flows of information and materials among network members, e.g. NPD, safety management, procurement, etc.	The flows within the network are organized according to the governance pattern

2.2 Consolidation of the three approaches

Figure 2 displays the consolidation of the three approaches (GMN, GEN, CbPF). First, the activities which companies perform to accomplish its operational objectives were identified: Idea Generation and Selection; Product Development; Sourcing; Production; Delivery; Services and Support; Disposal and Recycle; Support Activities.

Second the concepts which deal with the networking dimension were added to the scheme: Structure, Governance and Coordination, Processes and Infrastructure, Capabilities, and External Relationships. Context (mission, drivers, and barriers), a key element influencing Level 3, was considered influential in strategic decisions, and thus transversal to all other features mentioned.

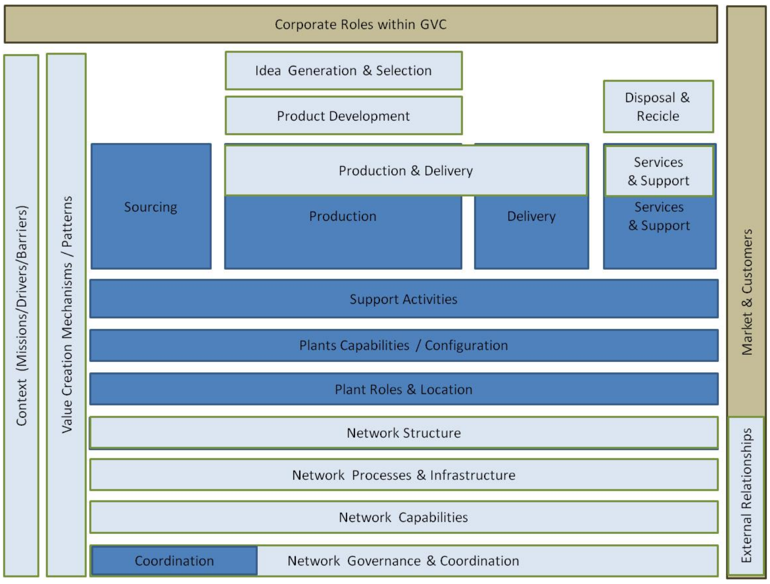

Fig. 2 – Integration of the elements of GEN (dark blue), GMN (light blue) and CbPF (brown). The authors.

2.3 Making the framework operational: constructs and variables

Finally, Figure 3 presents the consolidated, integrative framework, depicting the networks in three levels, and having the multinational firm at the very core of the analysis. It is noteworthy that the unit of analysis in the research is the network of subsidiaries (level 2), and not a specific subsidiary or one of its sites (level 1). As previously mentioned, the institutional environment must be taken into account as a source of drivers and barriers for the decisions concerning the mission and the shape of the firm's network of subsidiaries.

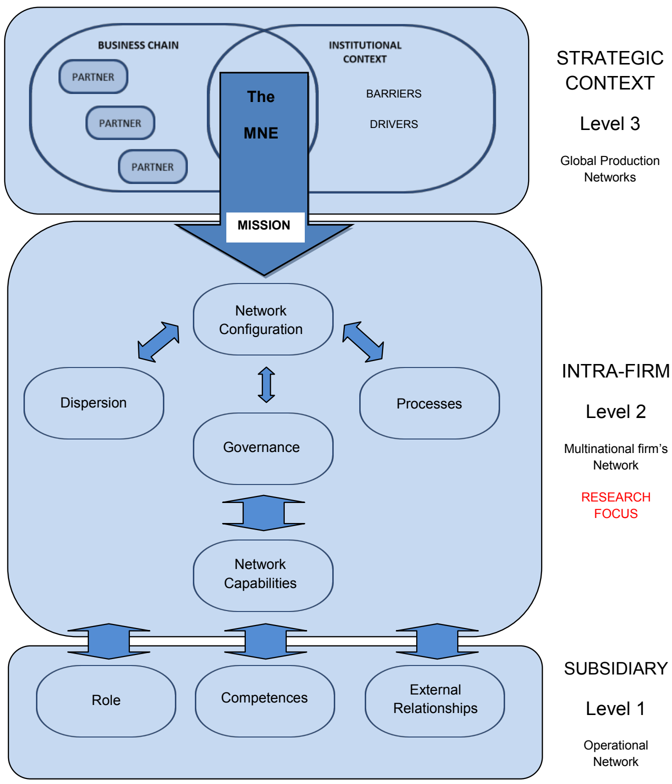

Fig. 3 – Consolidated framework with networks in three levels. The authors.

Defining the concepts - Level 3: strategic context - Global Production Networks

The analysis of manufacturing and engineering networks created by EMECs must consider the firm's mission and vision, as well as the main drivers and barriers. The GEN approach (Zhang and Gregory, 2011) has the following concepts:

a. Mission – Three key missions can be assigned to a firm's internal network:

- Efficiency-oriented – Adoption of mechanisms such as economies of scale/scope, international operations synergies, leveraging expertise or precious resources on a global scale, sharing and reuse of existing solutions;
- Innovation-oriented – Adoption of mechanisms such as customer intimacy, technology leadership, and market/technology-driven innovation, learning across disciplines or organizations, leaving room for creativity or diversity;
- Flexibility-oriented – Adoption of mechanisms such as flexible working approaches, mobile engineering resources, reconfigurable network structures, and local responsiveness.

b. Drivers – The driving forces for the networks, like dispersed and interrelated engineering operations, increasing changes and uncertainties, and increasingly capable ICT.

c. Barriers – Obstacles for global operations, like communication difficulties, economic and organizational barriers, and social and psychological barriers.

Defining the concepts - Level 2: intra-firm network

Network configuration

International manufacturing networks are classified according to the degree of plant dispersion and coordination conditions (Shi and Gregory, 1998). Seven configurations were identified, separated in four groups:

a. Regional Focus Networks – Low geographical dispersion and regional focus:

• Regional Uncoordinated Manufacturing Configuration

b. Global Export Networks – Low geographical dispersion and global orientation:

• Home Exporting Manufacturing Configuration

• Regional Exporting Manufacturing Configuration

c. Multidomestic Autonomy Networks – High geographical dispersion, strong autonomy in operations and weak coordination:

• Multidomestic Manufacturing Configuration

• Glocalised Manufacturing Configuration

d. Global Coordination Networks – High geographical dispersion with high global orientation and coordination:

• Global-Integrated Manufacturing Configuration

• Global-Coordinated Manufacturing Configuration

Network dispersion

The term expresses the degree of geographical concentration of a multinational's subsidiaries (Zhang and Gregory, 2011). For example, an intra-firm network concentrated in one economic bloc is rather different from other whose subsidiaries are scattered around the world.

Network governance and coordination

The concept of governance refers to the mechanisms to steer and control the network, including authority structures, performance measurement and coordination mechanisms (Zhang and Gregory, 2011).

Network processes and infrastructure

Based on Zhang and Gregory (2011), the cross-border flows (processes) that occur within the network might be:

- Product Flows (materials, components and products)
- Information Flows
- Knowledge Flows

The processes of Information and Knowledge are supported by

- Collaboration and Interaction Tools and Mechanisms
-

Network capabilities

Network configuration can be evaluated in terms of the capabilities it brings to firm (Fleet and Shi, 2005; Srai and Gregory, 2008). The capabilities used to evaluate configuration are:

a. Cost Efficiency

b. Customer Responsiveness

c. Resource Accessibility

d. Agility

e. Learning

f. Risk Management

g. Manufacturing Mobility

Defining the concepts - Level 1: subsidiary's operational network

Roles and Location

Depending on the profile of competences developed by the subsidiary and considering the taxonomy proposed (Ferdows, 1997), subsidiaries might be classified according to a more general role:

- Access to Low-Cost Production - Acting as Offshore or Source
- Access to Skills and Knowledge - Acting as Outpost or Lead
- Proximity to Market - Acting as Server or Contributor

Competences

Merging the Strategic Competences (Fleury and Fleury, 2007) to the concepts of Configuration and Support Activities (Fleet and Shi, 2005), the list of the competences developed at subsidiary level is as follows:

- Planning - Competence to identify, elaborate, implement and manage competitive strategies.
- Organization - Competence to design, implement and improve management systems.
- Technology - Competence to add value to products and processes
- Production - Competence to produce goods and services
- Plant Configuration – competence for layout and equipment
- Commercial - Competence to trade and deliver products and services
- HR Management - Competence to attract, contract, develop and reward people
- Finance - Competence to prospect, negotiate, invest and manage financial resources
- Customer Relationship - Competence to develop and manage market and customer relationships
- Supply Chain Management - Competence to define supply policies, develop and manage suppliers.

Market, Customer and Other Relationships

Customers are active players in the overall dynamics of the industry (Porter, 1985). Zhang and Gregory (2011) extend this importance of external relationships, referring to the interaction with other external partners, including suppliers, customers, users and collaborators.

3. THE INITIAL ANALYTICAL FRAMEWORK

From the previous discussion, it is now possible to elaborate a framework for the three layers of networks. The analysis and classification of the EMECs should begin with the strategic context, where firms are initially classified according to the type of industry they belong to, as well as according to the competitive strategy prevalent in each type of industry (Porter, 1985; Treacy and Wiersiema, 1995).

Tab. 2 – Framework for analysis and classification of EMECs. The authors.

Level 3 – Multinational company as a member of Global Production Networks						
Industry analysis	Manufacturing excellence (*) Cost leadership (**) Efficiency-oriented (***)		Innovative products (*) Differentiation (**) Innovation-oriented (***)		Customer orientation (*) Focused strategy (**) Flexibility-oriented (***)	
Position in GPN	Leader	Follower	Leader	Follower	Leader	Follower
Level 2 – Multinational company's network of subsidiaries						
Network configuration	Globally-Coordinated Manufacturing	Follows GPN's leader	Globally-integrated manufacturing	Follows GPN's leader	Multidomestic Autonomy Networks	Follows GPN leadership
Network dispersion	Moderate	Follows GPN leader	Low; concentrated	Low; concentrated	High	High
Network governance	HQ	GPN leader	HQ	GPN leader	Subsidiary	GPN leader
Network cross-border processes	Operations planning, Procurement, New production processes		New Product Development, knowledge transfer		Sales and Distribution planning	
Network capabilities	Cost-efficiency	Customer-orientation; flexibility-oriented	Rapid and coordinated scale-up;	Customer-orientation; flexibility-oriented	Customer-orientation; flexibility-oriented	Customer-orientation; flexibility-oriented
Level 3 – Subsidiary's operational network						
Role	Server or contributor	Source	Contributor	Source	Contributor	Source
Location	Low-cost sites	Low-cost sites	Regionally distributed	Regionally distributed	Close to clients	Close to leader
Key competences	Production	Production, Customer Relationship	Production R&D	Production	Marketing, Production, Product development	Production
External relationships	Weak	Moderate	Very weak	Moderate	Strong	Moderate
(*) According to Treacy and Wiersiema (1995) (**) According to Porter (1985)			(***) According to Shi and Gregory (1998)			

A distinction between firms that lead global production networks and firms which are followers in GPNs is made because that has a great influence in regards to the autonomy in terms of planning and implementing networks. In the first case, the firm has the power to make its own decisions whereas, in the second case, their network design and operations are influenced by the decisions made by the leader.

4 AN ILLUSTRATIVE APPLICATION OF THE FRAMEWORK

For illustrative purposes, five cases available in business management literature were examined through the "lenses" provided by the framework. They were four Chinese MNEs and one Brazilian MNE. Although the cases did not provide thorough description of the activities performed by those companies in terms of IOM, they were good enough for illustrating how the framework would work when applied in an EMEC's international operations management. The cases are:

- A Chinese autoparts producer with manufacturing and/or R&D facilities in 6 countries;

- A Chinese telecom equipment producer with manufacturing and/or R&D facilities in 17 countries;

- A Chinese home appliances producer with manufacturing and/or R&D facilities in 18 countries;

- A Chinese cosmestics producer with manufacturing and/or R&D facilities in 2 countries;

- A Brazilian cosmetics producer with manufacturing and/or R&D facilities in 6 countries.

A summary of the cases is on Table 3.

Networks	Components	Chinese EMEC 1	Chinese EMEC 2	Chinese EMEC 3	Chinese EMEC 4	Brazilian EMEC 1
Level 3 (strategic) GPN	Industry analysis and competence-based positioning in the industry's GPN	- Autoparts industry, with OEMs and after-market parts - Demand for lower prices by the carmakers caused a consolidation in the industry via mergers and acquisitions "forward" the chain - Prevalent strategy: cost leadership - ChEMEC 1 is a follower as a Developer and Manufacturer	- Home appliances industry, with increasing competition from emerging countries - Supply and production are verticalized, and the focus is on sales and distribution - Demand from new consumers requires more frugal approaches to product innovation - Prevalent strategy: differentiation - ChEMEC 2 is a follower as a Developer, Manufacturer and Service Provider	- Telecom equipment industry - Demand for cutting edge technologies forces companies to invest heavily in R&D - Prevalent strategy: differentiation - ChEMEC 3 is a leader as a Developer, Manufacturer	- Cosmetics industry - Global brands rule the market - Worries about sustainability and local cultures mobilize the consumers - Prevalent strategy: differentiation - ChEMEC 4 is a follower as a Developer, Manufacturer and Service Provider	- Cosmetics industry - Global brands rule the market - Worries about sustainability and local cultures mobilize the consumers - Prevalent strategy: differentiation - BrEMEC 1 is a follower as a Developer, Manufacturer and Service Provider
	- Mission	- Efficiency-oriented	- Innovation-oriented	- Innovation-oriented	- Innovation-oriented	- Innovation-oriented
	- Drivers	Increasing global consolidation	- Growing competition in home country forces to go global - Consolidation in the industry creates opportunities for acquisitions and learning	New sources of growth in the global marketplace	- The heritage of Chinese traditional medicine and its link to natural products	- The appeal of the Amazon forest and its link to biodiversity and natural products
	- Barriers	The fierce competition of incumbent multinationals	The fierce competition of incumbent multinationals	Legal restrictions in other countries, in terms of sensitive technologies	The fierce competition of incumbent multinationals and its rapid consolidation	The fierce competition of incumbent multinationals and its rapid consolidation
Level 2 (intra-firm) the MNE	Network Configuration	Globally coordinated manufacturing	Home exporting manufacturing	Globally coordinated manufacturing	Regional focus	Regional focus
	Network Dispersion	Scattered: 20 factories around China, US, Canada, Mexico, and Europe	Scattered: 8 industrial parks in China (including 18 design centers), 1 in North America, 2 Middle East, and 13 other factories spread around the world	Scattered: offices, plants and R&D facilities in 17 countries	Concentrated in 2 countries, although there is a vast sales and distribution network	Concentrated in 2 countries, although there is a vast sales and distribution network
	Network Governance	Centralized in Chinese HQ; strong horizontal coordination	Centralized in Chinese HQ; strong vertical coordination	Centralized in Chinese HQ, strong vertical coordination	Centralized in the Chinese HQ	Centralized in the Brazilian HQ
	Network Processes	Strong procurement process	Strong R&D and quality management processes	Strong product development	Strong distribution process	Strong distribution process, with direct sales
	Network Capabilities	Cost efficiency	Learning	Agility, Responsiveness	Responsiveness	Responsiveness
Level 1 (operational) subsidiaries	Roles and location	Proximity to automakers: subsidiaries are Servers or Contributors	Subsidiaries are Source or Outpost	Outposts, close to universities and industrial regions	Lead plants	Lead plants
	Competences and capabilities	Strong in production and technology (innovation)	Strong in production and technology (innovation)	Strong in technology (innovation)	Supply chain management	Supply chain management
	External relationships	Strong relationship with the customers (automakers)	Relationship with collaborators (R&D centers)	Relationship with collaborators (R&D centers and customers)	Relationship with collaborators (R&D centers)	Relationship with collaborators (R&D centers)

5 PLANNING THE FIELDWORK

As previously mentioned, the key questions to be addressed in studies about EMECs' internationalization are: How do EMECs conduct IOM? Are they developing new IOM models? What contributions the studies on EMECs' internationalization may bring to IOM theory? The framework just presented will be applied in seeking answers to those questions.

The field of research will involve Brazilian multinationals operating in China, and Chinese multinationals operating in Brazil. The multi-level analytical framework was developed for multiple case studies, with information being gathered at both the headquarters and subsidiaries.

Once the framework and the research instruments are tested and refined, cases will be conducted by analyzing level 3 first (GPN), then level 1 (subsidiary's operational network), while level 2 (intra-firm network), in which IOM concepts and variables are really ingrained, will be the last to be tackled.

•Step 1 – strategy analysis: level 3 network - GPN
Internal drivers and mission; external drivers and barriers
•Step 2 – subsidiary analysis: level 1 network
Its purpose and role in the intra-firm network; Competence assessment; Gap analysis
•Step 3 – intra-firm (MNE's headquarters and subsidiaries) analysis: level 2 network
MNE's network capabilities (configuration and governance)
•Step 4 – alignment analysis for the three networks

6 CONCLUDING REMARKS

This article presented a piece of an on-going research project aiming at a better understanding of international operations management in emerging country multinationals. That project focuses on Brazilian multinationals operating in China, and Chinese multinationals operating in Brazil.

The problem addressed in the article led to the development of an analytical framework capable of describing adequately the complex array of factors influencing the phenomenon: International Operations Management. It seems plausible to admit that its application may help in the advancement of research and theory making, as well as help managers to create innovative ways to design international operations.

A number of challenges remain, especially the refinement of the variables and indicators, the prioritization of their causal relationships and the research instruments.

REFERENCES

Bartlett, C., Ghoshal, S. (1998).Managing across borders: the transnational solution. Harvard Business School Press, Second Edition.

Contractor, F., Kumar, V., Kundu, S., Pedersen, T. (2010).Reconceptualizing the firm in a world of outsourcing and offshoring: the organizational and geographical relocation of high-value company functions.Journal of Management Studies. Vol. 47, Issue 8, pp. 1417–1433.

Ferdows, K. (1997). Making the most of foreign factories. Harvard Business Review, March, pp. 73-88.

Fleet, D., Shi, Y. (2005).A practical approach to applying theoretical concepts in the design of global manufacturing networks".Proceedings of 10th Cambridge International Manufacturing Symposium.September.

Fleury, A.; Fleury, M. (2007).The evolution of production systems and conceptual frameworks. Journal of Manufacturing Technology Management, 18 (8):949-965

Fleury, A.; Fleury, M. (2011) Brazilian multinationals: competences for internationalization. Cambridge: Cambridge University Press, 416 p.

Fleury, A.; Fleury, M.; Borini, F. ; Oliveira Jr, M.; Reis, G.; Silveira, F. (2010). Gestãoestratégica das multinacionaisbrasileiras.Research report.

Li, J.; Rugman, A. (2007). Real options and the theory of foreign direct investment, International Business Review, Elsevier, vol. 16(6), pages 687-712.

Mathews, J. (2006). Dragon multinationals: new players in 21st century globalization. Asia-Pacific Journal of Management, 23: 5-27

Porter, M. (1985), Competitive advantage: creating and sustaining superior performance, The Free Press, New York, NY.

Ramamurti, R. (2009). What have we learned about EMNEs? In Ramamurti, R. and Singh, J. (eds): Emerging multinationals from emerging markets. Cambridge, UK: Cambridge University Press.

Rugman, A.; Verbeke, A. (2001).Subsidiary-specific advantages in multinational enterprises. Strategic Management Journal, 22, 237-250.

Rugman, A.; Verbeke, A., Yuan, W. (2010).Re-conceptualizing Bartlett and Ghoshal's classification of national subsidiary roles in the multinational enterprise.Journal of Management Studies, Vol. 48, Issue 2, pp. 253–277, March.

Shafer, S., Meredith, J. (1998). Operations management: A process approach with spreadsheets. Wiley, New York.

Shi, Y., Gregory, M. (1998), International manufacturing networks: to develop global competitive capabilities, Journal of Operations Management, Vol. 16, pp. 195-214.

Srai, J., Gregory, M. (2008). A supply network configuration perspective on international supply chain development. International Journal of Operations & Production Management, Vol. 28 No. 5, pp. 386-411.

Vereecke, A., Van Dierdonck, R. (2002). The strategic role of the plant: testing Ferdows's model. InternationalJournalofOperationsandProduction Management, 22(5): 492-514.

Zhang, Y., Gregory, M. (2011).Managing global network operations along the engineering value chain.International Journal of Operations & Production Management.Vol. 31 No. 7, pp. 736-764.

Zhang, Y., Gregory, M., Shi, Y. (2008). Global engineering networks (GEN): drivers, evolution, configuration, performance, and key patterns. Journal of Manufacturing Technology Management, Vol. 19 No. 3, pp. 299-314.

Upgrading of EMNEs' Acquired Subsidiaries in Developed Countries: an Unintended Consequence of Asset-Seeking OFDI?

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Abstract

Despite the rise of emerging economies multinational enterprises (EMNEs) and their rapid internationalisation, we still know very liettle about the impact of their overseas foreign direct investment (OFDI) on host economies. The extant literature is dominated by discussion of the impact of developed countries multinational enterprises (DMNEs). Using a recent acquisition in the UK by a Chinese firm as case study and integrating the literature on subsidiary evolution, knowledge transfer and global value chains (GVC), this paper studies the impact of EMNEs on their newly acquired subsidiaries in developed countries particularly regarding the latter's capability upgrading. The findings demonstrate that the Chinese parent firm helped its newly-acquired subsidiary in product, process, functional and intersectoral upgrading. This seemingly counter-intuitive outcome is ascribed to the parent firm's strategy：upgrading of the subsidiary in developed countries was supported by the parent EMNEs precisely because of the latters' asset-seeking acquisition motive. The paper is the first study of upgrading in a hierachical governance structure with EMNEs as lead firms.

Key words: EMNEs, upgrading, international acquisition

1. Introduction:

Scholars have traditionally regarded multinationals as an invention of Western economies. But with the rapid development of a multi-polar world, they are no longer exclusive to the West (Mathews, 2002; Ramamurti, 2009). In fact, rapidly growing emerging market economies such as the BRIC (Brazil, Russia, India and China) countries are now producing home-grown MNEs at a phenomenal rate (Accenture, 2007; Boston Consulting Group, 2011).

The rise of the EMNEs has been accompanied by an unparalleled increase in outward foreign direct investment (OFDI) from emerging economies, which has risen rapidly from insignificant levels to reach a total value of $350 billion by 2008 (UNCTAD, 2009). EMNEs from the BRIC countries have been in the vanguard of this development (Gammeltoft et al 2010), led by China in particular, whose OFDI has become increasingly important to the global economy since 2001, following the announcement of the Chinese government's 'go global' policy and the resultant official encouragement given to Chinese businesses to internationalise (Alon et al, 2011). The value of

Chinese FDI outflows reached a new high of $68.1 billion in 2010 (an increase of nearly 22% on the previous year's figure), taking China to the 5th place amongst all global economies in terms of OFDI flows (MOFCOM, 2010). Over 13,000 Chinese firms were engaged in OFDI by the end of 2010, resulting in the creation of approximately 16,000 foreign subsidiaries, located across 178 countries in all five continents of the world (MOFCOM, 2011). A substantial part of this OFDI is now being committed to developed countries and regions such as the United States and the European Union, motivated by the search for strategic assets as well as by the search for markets (Buckley et al, 2007; Voss, 2011).

Taken together, the rise of the EMNEs and their increasing contribution to global OFDI flows have left many questions unanswered. There has been intensive debate, for example, on what drives the rise of EMNEs and their surging OFDI activities (Dunning, 2006; Mathews, 2006; Luo and Tung, 2007; Ramamurti, 2009; Rugman, 2009; Hennart, 2012). In addition, we know little about the impact of these EMNEs' OFDI on businesses in their host countries (Clegg and Voss, 2012) and this is the gap this paper endeavours to fill in.

In particular, by examining a case of Chinese firm's acquisition in the UK, the paper explores whether the acquisition has led to capability upgrading in the acquired firm. This is an interesting question because EMNEs are widely perceived as lacking ownership advantages and therefore it is difficult to imagine they have knowledge for businesses in developed countries to learn resulting in capability upgrading. On the other hand, there are recent studies suggesting that EMNEs do have ownership advantages and unique innovative capabilities (Ernst, 2008; He and Fallon, 2013; Yin and Williamson, 2011) and this opens the door for capability upgrading in their investing countries. In addition, the extant literature is dominated by discussions of the impact of developed countries MNEs on developing countries. According to our best knowledge, this is the first detailed study to examine the impact of EMNEs in developed countries.

The paper aims to integrate three strands of literature, i.e. global value chains (GVCs), subsidiary evolution and knowledge transfer. Insights from the GVC literature help to reveal areas where capability upgrading takes place whilst the other two strands of literature provide insights on why that happens in a hierarchical governance structure. Our theoretical contribution therefore lies with its integration of the above three literature.

2. Literature review

There has been, unfortunately, very little research on the impact of EMNEs' OFDI on businesses in host countries. There are three relevant strands of literature dealing with impact of multinational enterprises' (MNEs) overseas expansion on local businesses in host countries, all of which were dominated by discussion in the context of DMNE's internationalisation either in other developed countries or developing countries. Nevertheless, they do shed light on how the impact of EMNEs' OFDI on businesses in host countries could be understood.

The first strand is the subsidiary evolution literature. This literature was initially concerned with how foreign subsidiaries evolve as a result of head-office assignment. In particular, subsidiaries were perceived as knowledge inferior to their parents firms and therefore regarded only as receivers of knowledge (Michailova and Mustaffa, 2012). Later the focus shifts to the influence of subsidiaries' autonomous behaviour and local environment (Ambos et al., 2010; Birkinshaw and Hood, 1998; Collinson and Wang, 2012), recognising that subsidiaries could also be sources of knowledge (Michailova and Mustaffa, 2012). Despite its many insights and the recent surge of EMNEs' internationalisation, this strand of literature is still yet to study the evolution of EMNEs' overseas subsidiaries.

The second strand is the knowledge transfer literature which takes on knowledge flow more directly. This literature goes beyond the headquarter-subsidiary relationship to also include relationship between DMNEs and their business partners in host countries. Recognising that knowledge flow is a eminent feature of MNCs' internationalisation, this strand of literature studies knowledge exchange with local clusters, knowledge transfers between parent and subsidiaries and transfers between subsidiaries (Ghoshal and Bartlett, 1990; Mudambi and Navarra, 2004; Simona and Giroud, 2011). However and similar to the subsidiary evolution literature, this strand of literature was also dominated by the discussion of DMNEs. In addition, studies of knowledge transfer in the context of international acquisition are still rare. In particular, urgent research is needed in light of the rising international acquisitions by EMNEs (Birkinshaw et al., 2010).

Although the above two strands of literature address what and how knowledge transfer between parent firms and subsidiaries and how subsidiaries' roles evolve over time, they do not tackle the issue as to the impact of MNEs' internationalisation on upgrading of firms in their host countries. This is taken on by the global value chain (GVC) literature.

The GVC literature recognises globalisation of economic activities and ties the concept of value-added chain directly to the globalisation of industries (Morrison et al., 2008). It emphasises the key role played by lead firms from developed countries in coordinating or governing globally dispersed and organisationally fragmented production and distribution networks (ibid). Its primary concern is how global production and distribution systems are organised and governed which dictates what, how, when and how much is to be produced (Humphrey and Schmitz, 2002).

Many empirical studies have applied the GVC approach and pointed to the importance of MNEs from developed countries for firms in developing countries to continuously improve their products and processes and shift 'from low-value to relatively high-value activities in global production networks' (Gereffi, 2005: 171). The argument lies with the learning opportunities for local producers who are inserted into the global value chain via MNEs which are assumed to possess superior technologies and knowledge (Gereffi, 1999; Marin and Giuliani, 2011). This could lead to different types of upgrading: product upgrading where firms move into more sophisticated product lines increasing unit values, process upgrading so that firms produce more efficiently by re-organising the production system or introducing superior technologies, functional upgrading in which firms move up new functional areas in the value chain such as design or marketing to increase the overall skill content of activities, inter-sectoral upgrading which represents a horizontal move into new sectors with firms moving into new productive activities applying existing competences (Humphrey and Schmitz, 2002; Giuliani et al., 2005).

The essence of the GVC literature is based on the idea that upgrading and knowledge transfer are constrained by governance structure. The upgrading prospects depend on the governance structure of the value chains. It proposes four different governance structures that represent a continuum from loose to very tight relationships between global lead firms and local suppliers: arm's-length market relations, networks, quasi hierarchy and hierarchy (Humphrey and Schmitz, 2002). It further argues that different governance structures offer different upgrading opportunities: quasi-hierarchical chain offers favourable conditions for fast process and product upgrading but hinders functional upgrading; market-based relationships do not foster fast product and process upgrading but opens more room for functional upgrading; networks offer ideal upgrading conditions but are the least likely for developing country producers (ibid).

Empirical studies of the GVC literature, however, are also dominated by upgrading in developing countries and the role played by DMNEs as lead firms. Despite the rise of EMNEs, the literature is still yet to study them as global lead firms and the opportunities of upgrading they might bring to firms in their investing countries. In addition, within the literature the unit of analysis ranges from clusters to industries and nations but 'individual firms is never the central focus … although all [the studies] implicitly incorporate this dimension into the analysis' (Morrison et al., 2008). Moreover, although the literature proposes four different governance structures, the hierarchy structure, i.e. the relationship between headquarters and subsidiaries, has never been studied in detail.

Therefore the GVC literature does not offer many clues on upgrading in hierarchical value chains. On the other hand, the subsidiary evolution and knowledge transfer literature indicate that within the broad hierarchical structure there are different control and coordination mechanisms (Ghoshal and Nohria, 1989; Gupta and Govindarajan, 1991). This suggests there are actually different governance structures under the single umbrella of hierarchy. Therefore treating hierarchy as a single unifying governance structure could be misleading. In addition, it is further pointed out that what control mechanism is realised to a large extent relies on parent firms' strategies and the mandates assigned to subsidiaries (Ambos and Schlegelmilch, 2007). It is argued that the acquisition motives of the parent firm determine the relationship of the parent and its subsidiaries. In particular, if the motive of acquisition is asset-seeking, the acquired subsidiaries are likely to see their competence –creating efforts to be reinforced and they are expected to develop new products, technologies, practices and skills to the MNE network (Cantwell and Mudambi, 2005; Yang et al., 2008).

In this paper insights from these three strands of literature are integrated to investigate upgrading of EMNEs' foreign subsidiaries but also to offer a tentative explanation linking EMNEs' strategies with the upgrading outcomes. The unit of analysis of this paper is therefore firms and in particular EMNEs and their acquired subsidiaries in developed countries.

The selection of EMNEs and their acquired subsidiaries as subjects of study is novel in the GVC, subsidiary evolution and knowledge transfer literature. The extant literature is based on the assumption that MNEs as lead firms have superior technologies and know-how to be learned by firms in developing countries. However, it is widely perceived that Chinese MNEs and, indeed EMNEs in general, do not have firm-specific advantages in terms of innovative capabilities and organisational and management skills (Dunning et al., 2008; Rugman, 2008). Many scholars argue that EMNEs suffer from ownership disadvantages associated with their latecomer status (Mathews, 2006; Luo and Tung, 2007). It is therefore a big question as to whether their investment in developed countries is associated with knowledge transfer to and upgrading in local businesses in the host countries.

Because of its exploratory nature, the study will employ a case study approach and investigate a recent acquisition in the UK by a Chinese firm. Data is collected from secondary sources that consisted of information on relevant company websites and reports in both English and Chinese media. The intention is not to provide a comprehensive picture but to offer a tentative answer to the above question.

3. Times Electric's acquisition of Dynex

In spite of its relatively small volume, Chinese investment in Europe has been surging over recent years from a mere 189 million USD in 2005 to 6 billion USD in 2010 (MOFCOM, 2011). Chinese OFDI is highly concentrated within the EU with the UK and Germany being the top two major destinations. A recent study demonstrates a few interesting features of Chinese investment in EU including increasing participation of Chinese private enterprises as investors, a variety of entry modes, and diversifying range of industries in which they invest (Clegg and Voss, 2012).

In 2011, the UK received XX of Chinese investment, making China the third largest investor. Over the last few years there has seen a number of acquisitions in different industries including Shanghai Automotive Industry Corporation's (SAIC) take-over of MG Rover in the engineering industry, Bright Food's acquisition of a majority stake in the cereal maker Weetabix and the Chinese property developer Dalian Wandai's purchase of British yacht maker Sunseeker International.

In many of these cases, the acquired British firms were internationally well-known and held renowned brands. They tend to be medium-sized enterprises while their Chinese parent companies were considerably larger. Many of the acquired British firms had a long tradition and proud history and they were technology leaders in their sub-sectors.

This is also the case for the company we are studying. The origin of Dynex began in 1956 in Lincoln of the UK as AEI Semiconductors that manufactured some of the first silicon based semiconductor components in the world. Subsequent mergers and acquisitions have seen the business operating under the names of Marconi Electronic Devices, GEC Plessey Semiconductors and Mitel Semiconductors. Over the years the business has become one of the world's leading suppliers of specialist, high power semiconductor products. It designs and manufactures high power bipolar discrete semiconductors, power modules, including insulated-gate bipolar transistors (IGBTs), and high power electronic assemblies. Its products are widely used in power electronic applications including electric power generation, transmission and distribution, marine and rail traction drives, aircraft, electric vehicles, industrial automation and controls. In 2000, Dynex Power Inc., a small, publicly quoted Canadian company, formed Dynex Semiconductor Ltd to purchase the assets of Mitel Semiconductors and transferred all operations in Canada to Lincoln. However, this did not bring financial strength to the company. The company has seen its sales revenue fluctuating over the years and it has accumulated a significant level of debt. It was not able to fund the necessary capital expenditure programme to increase its capacity and efficiency. A few years later, its Canadian owner wanted to sell the company.

The opportunity was grasped by Zhuzhou CSR Times Electric Co. Ltd (hereafter Times Electric) which acquired 75% of stake in Dynex in October 2008. Times Electric is based in the Hunan Province of China. It is mainly engaged in the research, development, manufacture and sales of locomotive train power converters, control systems and other train-borne electrical systems, as well as the development, manufacturing and sales of urban railway train electrical systems. In addition, it is also engaged in the design, manufacturing and sales of electric components including power semiconductor devices for the railway industry, urban transit and non-railway purposes. Times Electric is listed on the Hong Kong stock exchange and majority owned by the CSR Group, the second largest railway equipment in China and one of the largest in the world. CSR Group is quoted in Shanghai and Hong Kong but is itself majority owned by the Chinese State–owned Asset Supervision and Administrative Commission.

4. Analysis and results

The acquisition by Times Electric in 2008 gives Dynex much improved access to the Chinese market which is less affected by the current economic problems. Mainly because of this, Dynex is still thriving whilst many other businesses are struggling. The number of employees at Dynex has grown from fewer than 250 in 2008 to 315 in 2013.

One of the most significant impacts is financial stability the parent company brought to Dynex. With financial support from Times Electric, Dynex built a 12 million pounds new R&D centre to focus on developing IGBT technology. Dynex's R&D team also increased from 12 in 2008 to about 40 in 2012. Times Electric also helped Dynex to secure finance and build two new IGBT fabrication lines with £12 million investment, upgrading its production facilities. In addition, the parent company helped to acquire the freehold of land and buildings used by Dynex in Lincoln, giving it greater flexibility for future development of the operational facilities and reducing long term overhead costs.

All these have proved to be transformational for Dynex in the last few years. Its sales revenue has grown from $30.2 million in 2007 to $39.6 million in 2012 with particularly strong growth in its IGBT product group despite the wider unfavourable economic environment. There has been major change in its revenue by region. Strong demand in China has seen the country's share of revenue increased from less than 10% in 2007 to 38% in 2012 whilst the share of Europe dropped from 68% to 38% in the same period. In a recent interview, Dr. Paul Taylor, President and CEO of Dynex, commented that Dynex is now able to compete on an equal footing with the world's top semiconductor makers, including Infineon of Germany, ABB of Switzerland, and Mitsubishi of Japan (China Daily, 2013).

The following discussion examines whether the take-over has helped Dynex to achieve capability upgrading. The analysis will draw upon the GVC literature and focus on four areas of industrial upgrading as indicated by the literature: product upgrading, process upgrading, functional upgrading and intersectoral upgrading.

4.1 Process upgrading

Since the take-over in 2008, Dynex has been able to upgrade its production facilities with the help of Times Electric. Dynex installed a new 6-inch bipolar thyristor wafer fabrication line in 2009 which enabled it to produce high power thyristor products. These products are suitable for use in high voltage direct current (HVDC) converter valves which are preferred for use in long distance electric power transmission and for the interconnection of national grid networks. The company later designed and built an advanced HVDC thyristor test facility in Lincoln to accelerate the development of high voltage thyristors used in HVDC electric grid systems and enable development at even higher voltage ratings (Dynex, 2010; 2011a).

In 2011 Dynex completed a £12 million, 21 month project to install two new 6-inch IGBT wafer fabrication production lines to upgrade and expand its fabrication facility for silicon chips to be used in insulated gate bipolar transistor (IGBT) modules. The new IGBT lines replaced its existing production line, which processed 4-inch diameter silicon. The existing facility was originally set up over 20 years ago to fabricate CMOS integrated circuits, and more recently the IGBT and fast recovery silicon chips that Dynex assembles to produce IGBT and diode power modules. The acquisition by Times Electric opened the door for Dynex to supply IGBT products for the rapidly expanding Chinese railway market. The company, however, realised that additional capacity and technology capability would be required to address this new opportunity. The new 6 inch IGBT wafer fabrication lines enabled it to increase production capacity approximately tenfold. In addition, the completion of these production lines has enabled large volume chip manufacture for the first time in the company's history.

As a result, the newly installed IGBT lines helped the company to achieve more than 2.5 times IGBT module revenue in 2011 compared to 2010. The power module group achieved revenue of $9.2 million in 2011, a growth of 155% over 2010 (Dynex, 2011a). In 2012, the power module group continue to grow significantly and become the second largest of Dynex product groups delivering sales of $15 million, a further increase of 63% over 2011 (Dynex, 2012).

With the completion of the two 6-inch fabrication lines, the company is well positioned to take advantage of the significant opportunities in China. Indeed, the largest portion of the project output has been sold to its parent company, Times Electric, who used the IGBT modules in applications such as railway equipment and high power motor drives. Dynex itself reckons that advances in its power module assembly and test techniques have led to improved reliability and robustness, improved manufacturability, and lay down the basis for new products that will incorporate the next generation of its IGBT and fast recovery diode chips (Dynex, 2011a).

Taking together, the newly installed and modernised 6-inch wafer fabrication production lines for both the IGBT and Bipolar groups have provided the recently established R&D centre (which will be discussed in more detail in the section of functional upgrading) with the on-site capability to develop new leading edge IGBT and bipolar products for manufacture in Dynex in Lincoln and Times Electric in Zhuzhou. Indeed, new technologies and new semiconductor products from the R&D centre can now be swiftly assembled in its neighbouring factory (Dynex, 2012).

Another change resulted from the fact that the company now offers smaller range of power modules and IGBT die parts as well as bipolar parts (this will be discussed in more detail in the section of product upgrading). Historically the company produced a very wide range of products with little ability to forecast which products would be wanted by customers. This meant that materials were ordered and parts were made in response to firm orders which, however, would lead to increased lead times. As a result of smaller range of products, the company is now able to offer reduced lead times by holding higher inventory levels.

4.2 Product upgrading

The current GVC literature refers product upgrading to situations where firms move into more sophisticated product lines increasing unit values (Humphrey and Schmitz, 2002). This has happened in Dynex since the take-over by Times Electric. The 6-inch bipolar thyristor wafer fabrication line installed in 2009, for example, has helped the company to increase capacity and extend power rating of its i2 thyristor products, leading to the release of the larger 125mm 8.5kV HVDC thyristors. The extension of the i2 range of thyristors continued through 2011 with the development of a 150mm thyristor. This will be the basic thyristor prior to implementing improved contacting technology and silicon edge profiling techniques that will lead the company into a new generation of high performance products. Combined with the new wafer fabrication facility, the improved thyrisitor technology and new purpose built high voltage test centre, Dynex is well positioned to develop leading edge thyristor technology for many years to come (Dynex, 2012).

During the second half of 2011, Times Electric transferred production of lower power (and therefore lower margin) bipolar products from Dynex to the parent company. This enabled Dynex to concentrate its bipolar business on the production of higher power, higher margin parts in future (Dynex, 2011a). In the R&D Centre which started operating in October 2010, the development rate of new products has accelerated. New products, such as the 1500A/3300V and 1600A/1700V IGBT modules, have been completed and put into application successfully in railway systems (Dynex, 2012).

Significant progress was also achieved in the development of a more advanced high voltage IGBT and fast recovery diode chip, new products developed from which will offer lower operating energy losses and increased power capability, rendering them suitable for both railway and electric grid applications. To accommodate more optimized silicon structures and fabrication processes, Dynex has redesigned its latest 3300v IGBT modules whose improved technical performance is on a par with the company's international competitors' products. With the support from Times Electric, Dynex also plans to produce IGBT and diode processes and designs compatible with manufacture using 8-inch silicon. These will offer increased capacity and the ability to service higher volume markets such as electric vehicles, wind turbines and solar power systems (Dynex, 2011a).

The two new 6-inch IGBT wafer fabrication production lines have expanded sales revenue from power module group products which has significantly changed the balance of sales between Dynex's different product groups. Traditionally the sale of bipolar products has been at the core of the company's business since 2000, accounting for between 60% and 75% of total revenue whilst the sale of power modules typically accounted for between 15% and 20% of total revenue. Following the completion and commissioning of the two new IGBT fabrication lines during the first half of 2011, the balance of sales has altered with the sale of bipolar products now accounting for 48% of the company's revenue in 2012 whilst the sale of power module and IGBT die now accounts for 38% of total revenue in the same year (Dynex, 2012).

The shift of sales balance towards the power module group does not necessarily mean an increase in unit values. However, this could still be viewed as a case of product upgrading because it at least demonstrates that Dynex is able to grasp the opportunity of increasing market demand that the company was not able to achieve before the acquisition. Indeed, with strong demand for IGBT modules from China, the trend is likely to continue with power module and IGBT die sales accounting for the majority of the company's business in future.

4.3 Functional upgrading

Functional upgrading is where firms move up new functional areas in the value chain such as design or marketing to increase the overall skill content of activities (Humphrey and Schmitz, 2002). Traditionally this is expected to happen in firms in developing countries where they move from simple assembly to downstream and upstream functions such as R&D, marketing and logistics.

In the first glimpse, functional upgrading seems impossible for Dynex as the company had a decent record in R&D and design and already fulfilled the function of marketing. However, the take-over by Times Electric has also brought changes into how R&D is undertaken in Dynex. A detailed examination of the company's annual reports suggests that in the past the company was not able to consistently maintain strong investment R&D. Indeed, before the take-over the company's R&D activities relied to a large extent on collaborative programmes with customers and key academic research partners or funded by government's grants. The take-over by Times Electric has seen not only the establishment of a brand-new R&D centre but also stable growth in R&D expenditure. The company spent 3.9% of its revenue on R&D in 2009 and this has been significantly increased to 10.6% in 2012 (Dynex, 2011a, 2012).

The growing expenditure on R&D not only helps to sustain and strengthen research and development activities but also reflects Times Electric's ambition to develop Dynex into a world leading industrial high power semiconductor. Indeed, Dynex has now set its sights on securing a long-term position amongst the top three semiconductor manufacturers based upon innovation and technical excellence. The company has taken initiative to develop new engineering skills for the future by encouraging the R&D team to increase its attendance at key power electronics workshops, seminars and conferences in Europe to ensure continued professional development of its workforce as well as seeking and recruiting the best staff from both the UK and China (Dynex, 2012).

Its R&D team has not only developed new sophisticated products such as the 3300v IGBT modules and prototypes of a 250 mm x 89 mm module but also made significant advances in the fundamental research for thyristors and IGBT technology for HVDC applications. Research is also undertaken on new materials for power devices (Dynex, 2012).

Another area of functional upgrading, although counter-intuitive at the first glimpse, is indeed in marketing. This is reflected in the agreement between Dynex and Times Electric in consolidating and integrating their sales and distribution channels for power semiconductors. According to the agreement, Dynex sales office is now responsible for all the power semiconductor products of Dynex and Times Electric sold in Europe. Outside China, products from both locations will be branded with the Dynex name (Dynex, 2011a).

4.4 Intersectoral upgrading

Intersectoral upgrading represents a horizontal move into new sectors with firms moving into new productive activities applying existing competences (Humphrey and Schmitz, 2002). Historically Dynex's power modules mainly found their applications in the marine drive sector. It is since it was acquired by Times Electric that new opportunities in the transport industry took off which has been reflected in the staggering growth in the last few year for IGBT modules as reported above. In 2011, the company successfully qualified and demonstrated, through field trials, the suitability of Dynex high power IGBT modules for use on China national locomotives and urban metro systems. This opens a massive market for the company to exploit for years to come.

The last two years has also seen the strategic focus of the company's R&D activity shift to develop new applications in the low carbon sectors such as railway transportation, renewable energy, smart grids and electric cars.

5. Discussion – EMNEs' asset seeking OFDI and upgrading of their foreign subsidiaries

This paper studies the upgrading of EMNEs' foreign subsidiaries in developed countries – an area that is rarely researched despite the surging overseas investment and acquisitions from emerging economies. Enlightened by the GVC literature, the case study illustrates how a technological advanced British company upgraded itself after being taken-over by a Chinese MNE. In particular, because of the support from its parent company, Dynex has been able to move up to and concentrate on more sophisticated product lines such as higher power bipolar products whilst at the same time transferring production of lower power bipolar products to its sister subsidiaries. In addition, the acquisition allows Dynex to access to the expansive Chinese market which was apparent in the company's explosive growth of its IGBT power group products. Process upgrading is particularly evident as seen in the new 6-inch bipolar thyristor wafer fabrication line and 6-inch IGBT wafer fabrication production lines replacing existing facilities. This not only enabled Dynex to significantly expand its production capability but also lead to improved reliability and robustness. Functional upgrading also happened as the company is now able to invest significantly and consistently in R&D and aims to be amongst the world's top three semiconductor manufacturers based upon innovation and technical excellence. Consequently the level and complexity of its R&D has been rising accordingly. The company is also now fully responsible for sales and distribution of all the products of itself and its parent company except for the market of China and America. The acquisition has also seen Dynex moving into new application markets such as renewable energy, smart grids and electric cars which therefore represents a case of intersectoral upgrading.

The GVC literature is therefore particularly helpful in illustrating capability upgrading of EMNCs' subsidiaries in developed countries. In addition, the role of lead firm (here refers to the parent company) is clear. Times Electric wanted to expand and upgrade Dynex's production capability and therefore the completion of new 6-inch bipolar thyristor wafer fabrication line and 6-inch IGBT wafer fabrication production lines. Times Electric also arranged and completed field trials to ensure Dynex high power IGBT modules' compliance with required standard so that they can be used on China national locomotives and urban metro systems. It is also Times Electric's specification of the goods to be produced that resulted in the massive expansion of IGBT power modules among other product groups. In addition, the ambition of Times Electric and its own parent CSR Corporation to become world-leading firms not only in the railway equipment sector but also in renewable industries helps to explain their massive investment in Dynex to further enhance the latter's R&D roles. Moreover, the fact that Dynex is finding applications of its products in new industries such as renewable energy and smart grids should be ascribed to its parent company's superior capability in 'grafting innovation' – finding novel uses and applications for existing technologies in additional industries (He and Fallon, 2013). All these call for more studies of EMNEs as lead firms in global value chains and global production networks and in particular their innovative capabilities and strategies in order to understand their impact on host countries. The discussion in the next section aims to illustrate how an understanding of their strategies can contribute to explain upgrading of their subsidiaries in developed countries.

Subsidiary upgrading and parent strategies

The evidence of upgrading in Dynex seems to be counter-intuitive. As discussed before, the extant GVC literature offers few clues for upgrading in hierarchical governance structure, but the subsidiary evolution and knowledge transfer literature direct us to pay attention to parent firm's strategies and their investment motives. So what indeed is the motive behind Times Electric's acquisition? To understand this, we have to switch the time back to a few years prior to the acquisition. Back then, Times Electrics and its own parent company, CSR Corporation, were already the main suppliers of China's railway equipment. However, Times Electric, despite it being the leading player in China regarding electric traction drives technologies, was not able to design and manufacture its own IGBT modules and silicon chips – the 'heart' of Electric Traction Drives – and had to rely on import. This constrained not only Times Electric and CSR's expansion in the railway industry but also their more recent penetration into the urban transit, wind power and electric vehicle industries as IGBT and its modules are also widely used in these industries.

In 2007, Times Electric initiated its IGBT R&D project with an 'acquisition – integration – innovation' strategy in order to develop a core competence in IGBT technology. Once it learnt the then Dynex owner wanted to sell the company, it acted quickly and completed the acquisition in 2008. What they targeted for was Dynex's technology know-how in IGBT and thyristors. The strategic asset-seeking motive is clear from, for example, the following comments of President of Times Electric after the completion of the acquisition:

"We expect Dynex to develop high power technology, R&D capability, and proven reliability and quality, thus to complement the rapidly growing manufacturing capability and power electric system know-how of Times Electric" (Dynex, 2008).

Times Electric finds it a winning formula by combining Dynex's technology capability and its own manufacturing advantage and system know-how. But it also gives Dynex an ideal platform to apply their technologies in the expansive market in China and therefore allow it to further improve its technologies. The last few years have seen Dynex's role in R&D and developing new products and technologies further reinforced confirming the prediction of Cantwell and Mudambi (2005) for competence-creating subsidiaries. New manufacturing facilities have been put into place including the 6-inch bipolar thyristor wafer fabrication line and 6-inch IGBT wafer fabrication production lines which enabled Dynex to produce new and better products. Its parent company helped it to move into and concentrate on more sophisticated product lines such as high power IGBT modules and high voltage and high power bipolar thyristors as lower power products were transferred to sister subsidiaries. The level and complexity of Dynex R&D has been rising accordingly. In addition, it is indeed Times Electric and its own parent CSR's 'diversification based on core competence' strategy (CNTV, 2012) and superb capability in grafting innovation (He and Fallon, 2013) that connected Dynex to new markets such as renewable energy, smart grids and electric vehicles and therefore intersectoral upgrading in Dynex.

In a ceremony to celebrate the completion of Dynex's new R&D centre, which also became its parent firm's R&D centre after integrating with Time Electric's existing R&D team, Mr. Changhong Zheng, President of CSR, emphasised that the R&D centre will focus on developing new technologies and products to expand the high power semiconductor product portfolio of both Dynex and CSR Times Electric noting that these products are key to a wide range of industries including rail transportation, electric vehicles, wind power generation, solar power, electric power grids and high voltage power conversion (Dynex, 2011a). Clearly Times Electric and CSR Corporation want to maintain and strength Dynex's role in technological development so that new advanced technologies could help them to maintain and strengthen their position in the rail equipment market but also conquer new markets.

Therefore although Times Electric had a strategic asset-seeking motive regarding its acquisition of Dynex, it does not represent a case of asset-stripping as feared by many in developed countries. Dr. Paul Taylor admitted in a recent interview:

"Back then, there was a lot of bad press about Chinese acquisitions, including the movement of manufacturing to China, and technology being taken away," (CNTV, 2012)

In contrast, Times Electric tried hard to help its newly acquired subsidiary to upgrade so that existing capabilities could be strengthened and new and advanced capabilities be developed in Dynex which, combined with its existing competences in large-scale manufacturing and system know-how, would create new advantages for Times Electric and CSR Corporation. Therefore, in the process of upgrading, knowledge also flow from Times Electric to Dynex regarding, for example, product quality and standards and new application areas for existing technologies. This confirms the findings of Yang et al. (2012) in that MNE parents with competence-creating motive transfer significant knowledge to acquired subsidiaries despite they study developed countries MNEs and subsidiaries in developing counties while our study is the opposite.

It is probably because of the intention to strengthen and further develop Dynex's technology capability that Times Electric deliberately gave it sufficient autonomy after the acquisition. Among the eight board members after the acquisition, only four were from Times Electrics. The parent company only occupied two seats in the current five members of board. Times Electric clearly recognised the importance of cross-cultural management and mutual trust between the British side and the Chinese side.

6. Conclusion

Using a recent acquisition in the UK by a Chinese firm as case study, this paper aims to examine the impact of EMNEs on their newly-acquired subsidiaries in developed countries particularly regarding the latter's capability upgrading. The finds are to some extent counter-intuitive: there has been upgrading in the Chinese firm's newly-acquired subsidiary in the UK and this is partly because of the parent company's asset-seeking or home-base augmenting motive of FDI and therefore the competence-creating mandate (Cantwell and Mudambi, 2005) in its subsidiary.

The paper represents a study of upgrading at the firm-level in the context of hierarchy as governance structure which is rare in the GVC literature. Interestingly we did not observe parent's tight control over its subsidiary as one would expect from the discussion in the GVC literature. Another recent research on Chinese acquisition in Germany had similar findings (Knoerich, 2012). It remains to be seen whether this is the pattern of Chinese asset-seeking acquisitions in developed countries. In addition, upgrading in Dynex – a competence-creating subsidiary - was supported by Times Electric partly because of its asset-seeking acquisition motive. This suggests parent firm's strategies and investment motives may act as a moderator on the impact of GVC on upgrading which needs to be further researched.

The policy implication of this study is significant. Many developed countries have an ambivalent attitude towards Chinese investment. On one hand, they are longing for the badly-needed investment. On the other they have concerns of asset-stripping and transparency of Chinese investment (Clegg and Voss, 2012). If the findings of this study could be generalised, then developed countries should at least absolutely welcome asset-seeking or home-base augmenting investment from China and other developing countries because they help capability upgrading in local businesses in developed countries in addition to employment and other benefits. Further research is needed to study what can be done to maximise the resulting technological and economic advantages from developing countries' asset-seeking overseas investment.

Reference:

Accenture (2008), Multi-Polar World 2: The Rise of the Emerging-Market Multinational, London.

Alon I, Child J, Li S, McIntyre JR (2011) Globalization of Chinese firms: theoretical universalism or Particularism, *Management Organisation Review*, 7.2, pp191–200

Ambos, B. and Schlegelmilch, B.B. (2007) Innovation and control in the multinational firm: a comparison of political and contingencey approaches. Strategic Management Journal 28: 473-486

Ambos, T.C., Andersson, U. and Birkinshaw, J. (2010) What are the consequences of initiative-taking in multinational subsidiaries? Journal of International Business Studies 41: 1099-1118

BIS (2008) Innovation Nation White Paper, the Department for Business, Innovation & Skills.

Birkinshaw, J. and Hood, N. (1998) Multinational subsidiary evolution: capability and charter change in foreign-owned subsidiary companies. Academy of Management Review 23 (4): 773-795

Birkinshaw, J., Bresman, H. and Nobel, R. (2010) knowledge transfer in international acquisition: a retrospective. Journal of International Business Studies 41: 21-26

Boston Consulting Group (2011), "The 2011 BCG Global Challengers: Companies on the Move – Rising Stars from Rapidly Developing Economies Are Reshaping Global Industries" [Online] https://www.bcgperspectives.com/content/articles/globalization_companies_on_the_move_2011_global_challengers, accessed 12 June 2012.

Bruche, G. (2009) 'The emergence of China and India as new competitors in MNE's innovation networks', Competition & Change 13 (3): 267-288

Buckley, P. J., Clegg, L. J., Cross, A.R., & Liu, X. (2007), The Determinants of Chinese outward foreign direct investment", Journal of International Business Studies, 38.4, pp. 499-518.

China Daily (2013) A fitting acquisition. [online] http://usa.chinadaily.com.cn/weekly/2013-01/25/content_16172821.htm, accessed 26 March 2013

Collinson, S. and Wang, R. (2012) The evolution of innovation capability in multinational enterprise subsidiaries: dual network embeddedness and the divergence of subsidiary specialisation in Taiwan, Research Policy 41: 1501-1518

Clegg, J. & Voss, H. 2012, Chinese Overseas Direct Investment in the European Union, Europe China Research and Advice Network, London.

CNTV (2012) Riding on the track of innovation – development of CSR innovation base in Zhuzhou (in Chinese) [online] http://news.cntv.cn/china/20120829/103198.shtml, accessed 6 June 2013

Driffield, N. and Love, J. H. (2007) Linking FDI Motivation and Host Economy Productivity Effects: Conceptual and Empirical Analysis, Journal of International Business Studies, 38 (3): 460-473

Dunning JH (2006), Comment on dragon multinationals: new players in 21st century globalization, Asia Pacific Journal of Management, 23.2, pp139–141.

Dunning JH, Kim C, Park D. 2008. Old wine in new bottles: a comparison of emerging-market TNCs today and developed-country TNCs thirty years ago. In The Rise of Transnational Corporations from Emerging Markets: Threat or Opportunity? Sauvant K (ed). Edward Elgar: Northampton, MA

Dynex (2008) Dynex Completes Plan of Arrangement. [online] http://www.dynexpower.com/news/60, accessed 6 June 2013.

Ernst, D (2008) Can Chinese IT Firms Develop Innovation capabilities Within Global Knowledge Networks? Economic Series No. 94 East-West Centre Working Papers

Gammeltoft P, Barnard H and Madhok A (2010), Emerging multinationals, emerging theory: macro-and micro-level perspectives, Journal of International Management, 16.2, pp95-101

Gereffi, G. (1999) International trade and industrial upgrading in the apparel commodity chain, Journal of International Economics 48: 37-70

Gereffi, G. (2005) 'The Global Economy: Organisation, Governance, and Development', in N.J. Smelser and R. Swedborg (eds) The Handbood of Economic Sociology, pp. 160-82. Princeton, NJ: Princeton University Press

Ghoshal S, Nohria N. 1989. Internal differentiation within multinational corporations. Strategic Management Journal 10(4): 323–337

Ghoshal, S., & Bartlett, C. A. 1990. The multinational corporation as an inter-organizational network. Academy of Management Review, 15(4): 626-646.

Giuliani, E., Pietrobelli, C., & Rabellotti, R. 2005. Upgrading in global value chains: Lessons from Latin American clusters. World Development, 33(4): 549–573

Gupta AK, Govindarajan V. 1991. Knowledge flows and the structure of control within multinational corporation. Academy of Management Review 16(4): 768–792

He, S. and Fallon, G. (2013) Chinese Multinational Enterprises' Firm-specific Advantages and a Critic on the International Business Theory, Paper presented at the 40th AIB-UKI annual conference, Birmingham, 21-23 March 2013

Hennart J-F (2012), Emerging market multinationals and the theory of the multinational enterprise', Global Strategy Journal, 2.3, pp168-187

Humphrey, J. and Schmitz, H. (2000) 'Governance and Upgrading: Linking Industrial Cluster and Global Value Chain Research', IDS Working Paper 120, Brighton: IDS

Humphrey, J. and Schmitz, H. (2002) How does insertion in global value chains affect upgrading in industrial clusters? Regional Studies 36 (9): 1017-1027

Knoerich, J. (2012) Gaining from the global ambitions of emerging economy enterprises: an analysis of the decision to sell a German firm to a Chinese acquirer. Journal of International Management 16: 177-191

Luo Y and Tung RL. (2007), International expansion of emerging market enterprises: a springboard perspective. Journal of International Business Studies, 38, pp481–498.

Marin A. and Giuliani E. (2011) MNE subsidiaries' position in global knowledge networks and local spillovers: Evidence from Argentina, Innovation and Development 1 (1), 91-114

Mathews JA (2002), Competitive advantages of latecomer firms: a resource-based account of industrial catch-up strategies. Asia-Pacific Journal of Management 19.4, pp 467–488.

Mathews JA.(2006), Dragon multinationals: new players in 21st century globalization. Asia Pacific Journal of Management 23, pp5–27.

MOFCOM (2011) 2010 Statistical Bulletin of China's Outward Foreign Direct Investment, Ministry of Commerce, People's Republic of China, Beijing

Morrison, A., Pietrobelli, C. and Rabellotti, R. (2008) Global value chains and technological capabilities: a framework to study learning and innovation in developing countries, Oxford Development Studies 36 (1): 39-58

McDermott, G.A. and Corredoira, R.A. (2010) Network composition, collaborative ties, and upgrading in emerging-market firms: lessons from the Argentine autoparts sector, Journal of International Business Studies 41: 308-329

Michailova, S. and Mustaffa, Z. (2012) Subsidiary knowledge flows in multinational corporations: research accomplishments, gaps and opportunities. Journal of World Business (47): 383-396

MOFCOM (2010 and 2011), Statistical Bulletin of China's Outward Foreign Direct Investment (Non Finance Part), Beijing: MOFCOM and National Bureau of Statistics of the People's Republic of China.

Mudambi, R., & Navarra, P. 2004. Is knowledge power? Knowledge flows, subsidiary power and rent-seeking within MNCs. Journal of International Business Studies, 35(5): 385-406.

NDRC, MOST, MOFCOM and SIPO, (2007), Current priority to the development of high-tech industry key field guide, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Commerce, the State Intellectual Property Office, Beijing.

Ramamurti R. (2009), What have we learned about emerging market MNEs? In Emerging Multinationals in Emerging Markets, Ramamurti R, Singh J (eds). Cambridge University Press: Cambridge, U.K.; 399–426.

Rugman A (2008), Do we need a new theory to explain emerging market multinationals? Paper presented to the 'Five-Diamond International Conference Cycle: Conference 1: Thinking Outward: Global Players from Emerging Markets', Columbia University, New York, 28-29 April 2008

Rugman A. (2009), Theoretical aspects of MNEs from emerging countries. In Emerging Multinationals in Emerging Markets, Ramamurti R, Singh J (eds). Cambridge University Press: Cambridge, U.K.: 42–63.

Voss, H. (2011), The determinants of mainland Chinese outward foreign direct investment, Edward Elgar: Cheltenham

Schmitz, H. & Strambach, S. (2009) 'The organisational decomposition of innovation and global distribution of innovative activities: insights and research agenda', International Journal of Technological Learning, Innovation and Development 2 (4): 232-249

Simona, G-L.and Giroud, A. "Knowledge transfer from TNCs and upgrading of domestic firms: A study from the Polish automotive sector." *World Development 40 (4): 796-807*

The Economist (2010) The World Turned Upside Down: A Special Report on Innovation in Emerging Markets.

UNCTAD (2005) Transnational Corporations and the Internationalisation of R&D, Geneva: United Nations Conference on Trade and Development

UNCTAD (2009). World Investment Report, 2009. Transnational corporations, agricultural production and development. UNCTAD, New York & Geneva

Yang, Q., Mudambi, R. and Meyer, K. E. (2008) Conventional and Reverse Knowledge Flows in Multinational Corporations, Journal of Management, 34 (5): 882-902

Yin, E. and Williamson PJ (2011) Competitiveness of Chinese emerging multinationals through new approaches to innovation, paper presented at the international conference 'Re-assessing Emerging Market Multinationals' Evolving Competitive Advantages', Cambridge, UK, 25-27 March 2011

Do French Companies Prepare Their Supply Chains to Face Sustainability Issues?

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Abstract
Environmental scanning seeking information about the organization's environment to identify the forces driving change should be important for firms preparing their supply chains to sustainability. Based on previous literature and on an in-depth qualitative research, the research presents a quantitative survey to characterise French organizations' sustainable supply chain scanning (SSCS) practices. Results confirm the existence of SSCS for more than 70% of the respondents, mainly linked to future projects. Scanning organization is informal, local (specific to departments), individual, and mostly opportunistic. The main themes are related to laws/regulations and downstream supply chains changes. The monitoring of actors is very broad. Clients and competitors seem to be particularly scanned, but the analysis shows a balance between the identified environmental components. Finally, SSCS appear to be latent with a broad scope of scanning. Cluster analysis does not show off any secant group attesting a high level of SSCS commitment.

Keywords: Supply chain management, Sustainable development, Environmental scanning, Survey.

1. Introduction

Sustainability today cannot be overlooked by firms under pressures from both legislation and public opinion (Jayaraman et al., 2007) and its importance in operations and supply chain management (SCM) keeps on growing. SCM can be considered as a main source of problems (particularly environmental ones due to greenhouse gas emissions) and as a lever for sustainable improvement through the re-configuration of supply chains (Fabbe-Costes et al., 2011a). Sustainable SCM (SSCM) is now a mainstream concern for researchers and practitioners (Kleindorfer et al., 2005) arguing that sustainability in supply chains can lead to various strategic benefits: improved corporate reputation (Roberts, 2003), better operational and financial performance (Rao and Holt, 2005; Carter and Rogers, 2008) and competitive advantage (Markley and Davis, 2007). Companies have thus developed sustainable initiatives

(Zhu et al. 2008) often restricted to one single dimension (Beske et al., 2008; Klassen and Verecke, 2012) of the so-called triple bottom line (Elkington, 1997). Despite the growing number of SSCM publications, there remains "*numerous opportunities for further advancing theory, methodology and the managerial relevance of future inquiries*" (Carter and Easton, 2011, p. 46) particularly because "*there are still fundamental issues researchers need to address in order to offer managers prescriptive models of how to create sustainable supply chains*" (Pagell and Wu, 2009, p. 37). Authors mainly call for new methods or frameworks to grasp future trends requiring supply chains'evolutions (Fabbe-Costes et al., 2011b) and for an extended approach of the firms' external environment (Zhu et al., 2008; Wolf, 2011) in so far as a firm cannot be more sustainable than its supply chain (Krause et al., 2009). Firms must be prepared to consider broad environmental and social issues (Kleindorfer et al., 2005, Kovács, 2008), to look at "*a longer part of the supply chain*" (Seuring and Muller, 2008) and to recognize the main role played by inter-organizational issues (Gold et al., 2010). Consequently, we assume that environmental scanning (ES) that seeks information about the organization's environment to identify the forces driving change should be important for firms preparing their supply chains to sustainability.

Our intent is thus to study SSCS firms' practices to understand how firms get prepared to face sustainable issues for their supply chains. In order to study SSCS firms' practices, we reviewed (section 2) environmental scanning literature and SSCM literature and identified a gap: the fields of sustainability, supply chain management and environmental scanning seem disconnected so far, except for very recent works. Section 3 presents the methodology for the exploratory quantitative research and section 4 the results. We conclude by research outputs and avenues for further investigations.

2. Theoretical and empirical background

2.1. Environmental scanning: a research trend lacking renewal

ES is a search information activity, which aim to grasp and anticipate events and relationships in a firm external environment (Hambrick, 1982; Lesca et al., 2012). ES was born within the field of strategic management in the late sixties (Etzioni, 1967). Firstly focused on managers' individual scanning practices (Aguilar, 1967), ES has been studied later as a corporate activity (Fahey and King, 1977) supported by various organizational systems from the allocation of human, financial and technological resources within firms' functional activities to the implementation of scanning dedicated units (Stubbart, 1982). Typologies of ES (Fahey et al., 1981) advocated formal approaches as advanced forms of scanning. Empirical studies led to contrasted results revealing hybrid organizational dispositions (Roussat, 1996) confirming that there is no ideal structure for scanning (Lenz and Engledow, 1986; Preble et al., 1988), and that scanning organizational approaches have to adapt to firm's characteristics (Herring, 1988).

Another main concern in ES is the environmental information to be targeted. ES papers generally recommend using a scanning scope as broad as possible in so far as "*under conditions of uncertainty, a complete and accurate scanning of the environment is critical*" (Srinivasan et al., 2011 p. 263). Nevertheless, considering the huge amount of information to be analysed, authors – somewhat contradictorily – suggest to focus scanning operations, delineating a more restricted scanning scope using check-lists of environmental components (Jain, 1984; Mendonça et al., 2004; Oreja-Rodriguez and Yanes-Estevez, 2007), including cognitive dimensions (Slaughter, 1999; Voros 2001, 2003) or prioritizing scanning targets thanks for example to experts' interviews (Calori, 1989) or importance/likehood criteria (Stoffels, 1982; Aaker, 1983; Bates, 1985). As the whole, empirical studies are focused on the scanning scope on economic and technological information (Jain, 1984; Subramanian et al., 1993) and a subtle enlargement of the scanning scope over time. Holmberg and Cummings (2009, p. 177) note that there is "*always a local search problem in firms environmental scanning*" and Xu *et al.* point out that "*executives in high performing companies tend to scan their environment more broadly than their counterparts in low performing one*" (2003, p. 382).

Over the past 40 years, the ES literature has evolved in different phases (Wong and Hung, 2012) focusing on the systems and tools employed by large firms then studying scanning practices in different contexts worldwide, but suffers from a lack of evolution: *"A review of the state of the art in environmental scanning does not reveal any major change in its basic methods since the 1970's"* (Tonn, 2008, p.596). Indeed, our literature review reveals a surprising gap: up until now, ES has not paid much attention to SCM nor sustainability issues. ES literature is still firm-focused and hardly mentions inter-organizational dimensions. Even if sustainability, by essence, mandates firms to look at their future (Tilley and Fuller, 2000; Kelly et al., 2004), ES literature is really sparse on that topic!

2.2. Towards sustainable supply chain scanning (SSCS)?

Few SCM papers consider ES as a main topic, emphasizing its positive impacts: competitive advantage (Badri et al., 2000), commercial information acquisition (March and Hevner, 2007; Kristal et al., 2010), quick response to market trends and disruption risks (Harland et al., 2003; Braunscheidel and Suresh, 2009) or better identification of suppliers (Choi and Kim, 2008, Koufteros et al., 2012). A few publications mention that ES is or should be important in the seek for sustainability (Voros, 2001; Schlange, 2006; Adema and Roehl, 2010; Asif et al., 2011) while some isolated ones refer to the practices of ES for sustainability in various contexts (Ngamkroeckjoti and Johri, 2000; Jamail and Mirshak, 2007; Will, 2008; Clemens, 2009). In the end, we can conclude that up until now ES, SCM and sustainability are not really connected in research, and we could not identify any articles exploring the scope or the organization of SSCS.

Earlier qualitative work (Fabbe-Costes et al., 2011a, b, c) which begins to address this gap, gave encouraging results about the existence and nature of such activities in French firms and wrote out guidelines to study SSCS practices that combine 1) how SSCS is organized, 2) what are the themes and actors monitored[1]. This paper is based on these guidelines and presents the results of a quantitative approach launched to study SSCS practices.

3. Methodology

The research was undertaken as a part of a major government-sponsored national research initiative in France (Predit 4, 2012) and was funded by the French Environment and Energy Management Agency (ADEME). As one of the goals of the research is to characterise French organizations' sustainable supply chain scanning (SSCS) practices, we seek to study actual managerial practices and perceptions using a survey instrument.

[1] Other topics, that are not considered for the present paper, have been studied in the qualitative work.

3.1 Data

Given the context, the focus of the fieldwork targeted firms and institutions operating on the French territory. Using professional networks (which list is available upon request), we sampled a broad range of managers able to answer (i.e. general managers, scanning, logistics or sustainable activities managers). The questionnaire was designed, pretested, revised, and online administrated through announces on the networks' WebPages/newsletters or through e-mailing campaigns. From May to October 2012, the survey was available online supported by SurveyMonkey.

399 respondents have accessed the survey and answered the first question. 133 respondents filled in the whole questionnaire. That high dropout rate, mainly on first and second questions, yet constitutes a first result. A likely explanation is the high exploratory nature of the research and the decreasing interest for sustainable development in France attributable to growing economic difficulties and lower commitment of the government to sustainable politics. Among the 133 respondents, 22,6% are CEO or logistics/SCM managers. The assessment of the responsibility and knowledge level about scanning, logistics/SCM and/or sustainable development revealed that only 5,2% had both low responsibility and low knowledge level. They were excluded from the analysis to obtain finally 126 exploitable questionnaires. Among these, 43,7% are involved in transport or logistics activities showing that managers which core business is logistics are probably more concerned by supply chain evolutions for sustainable development and/or more interested in developing scanning activities related to these questions.

3.2 Measures

As the research remains exploratory, we deliberately chose a descriptive and inductive approach with no hypothesis formulation. We generated the sample items using the results of the qualitative approach of Fabbe-Costes et al. (2011c). To depict SSCS practices, we structured the questionnaire (available upon request) around several thematics. We used multi-items measures for most of the variables. This paper presents the results obtained for three thematics: the organization of SSCS, the actors and themes monitored. Organization of SSCS items were measured using five-point Likert scales, usually anchored by "strongly disagree" and "strongly agree". Themes monitored and actors monitored items were measured using five-point importance degree scale.

The objectives were first of all to study each item separately (through mean and dispersion measures) and then to identify main dimensions characterizing each thematic through principal component analysis (PCA). Principal component analysis enables us to create summated scales explaining these thematics in terms of their common underlying dimensions (Hair et al., 1998). Considering our research objective, we have chosen to keep the most breadth of information to characterise French organizations' SSCS practices, without following a scale purification process. We used both scree-test criterion and percentage of variance criterion to determinate the number of factors. Promax rotations with Kaiser normalization were then used to improve results.

Based on PCA results, we finally conducted cluster analysis in order to make scanning profiles emerge as its *"objective is to classify a sample of entities (individuals or objects) into a small number of mutually exclusive groups based on the similarities among the entities"* (Hair et al., 1998, p. 15). As we are in an exploratory design, we used exploratory hierarchical clustering analysis methodology: the number of clusters was specified by dendogram and Ward's method (i.e. a hierarchical clustering procedure). Profiling clusters were conducted with final cluster centers, which enables to describe the clusters.

4. Results

4.1. Organization of SSCS

Table 1 presents the results of the descriptive analysis concerning the organization of SSCS. Results confirm the existence of scanning practices related to sustainable supply chains for more than 70% of the respondents, mainly linked to future projects.

Table 1. Frequencies, means and standard deviations of organization of SSCS

	1- SSCS organization							
	Frequencies					Mean	Std deviation	Std error
	I strongly disagree				I strongly agree			
1.7 We initiate SSCS in relation with projects	16 (12,7%)	16 (12,7%)	18 (14,3%)	40 (31,7%)	36 (28,6%)	3,51	1,361	,121
1.1 We develop SSCS practices	17 (13,5%)	16 (12,7%)	24 (19,0%)	31 (24,6%)	38 (30,1%)	3,45	1,389	,124
1.8 SSCS takes place within general or functional management	25 (19,8%)	16 (12,7%)	17 (13,5%)	45 (35,7%)	23 (18,3%)	3,2	1,409	,125
1.5 SSCS forms part of some employees' mission	26 (20,6%)	19 (15,1%)	20 (15,9%)	29 (23%)	32 (25,4%)	3,17	1,486	,132
1.6 SSCS is undertaken by departments for their own needs	19 (15,1%)	22 (17,5%)	36 (28,6%)	37 (29,4%)	12 (9,5%)	3,01	1,21	,108
1.2 Each one spontaneously undertakes SSCS for its own needs	17 (13,5%)	26 (20,6%)	35 (25,8%)	40 (31,7%)	8 (6,3%)	2,97	1,152	,103
1.11 SSCS information formally circulate	46 (36,5%)	20 (15,9%)	26 (20,6%)	25 (19,8%)	9 (7,1%)	2,45	1,348	,120
1.3 SSCS is a formalized process	45 (35,7%)	31 (24,6)	26 (20,6%)	16 (12,7%)	8 (6,3%)	2,29	1,253	,112
1.9 A SSCS structural entity exists	63 (50,0%)	17 (13,5%)	11 (8,7%)	16 (12,7%)	19 (15,1%)	2,29	1,544	,138
1.4 SSCS relies upon information systems	52 (41,3%)	26 (20,6%)	21 (16,7%)	18 (14,3%)	9 (7,1%)	2,25	1,32	,118
1.10 We use information providers to operate SSCS	58 (46,0%)	16 (12,7%)	29 (23,0%)	14 (11,1%)	9 (7,1%)	2,21	1,323	,118

***Nota1**: Results are presented following decreasing mean*

***Nota2**: In the table, most important results are enhanced in colour.*

SSCS organization is informal (items 1.11, 1.3, 1.4), local (specific to departments for their own business – item 1.8), individual (specific to individuals for their own activities – item 1.6), and thus mostly opportunistic (initiated for specific needs). A large majority of respondents clearly consider that there is no structural entity in charge with SSCS within their organization (item 1.9).

PCA (Table 2) structures the organization of SSCS in two dimensions:

- **'Formal organization'** (component 1) relying mainly on 'SSCS relies upon information systems (0.866), 'SSCS is a formalized process' (0.823), 'SSCS information formally circulate (0.817), 'we use information providers to operate SSCS' (0.790) and lower on 'a SSCS structural entity exists' (0.663);
- **'Opportunistic organization'** (component 2) relying mainly on 'we initiate SSC activities in relation with projects' (0.878), 'each one spontaneously undertakes SSCS for its own needs' (0.807), 'SSCS is undertaken by departments for their own needs

(0.744), 'we develop SSCS practices' (0.735) and lower on 'SSCM takes place within functional or general management'.

Table 2. Component matrix from organization of SSCS Component Analysis

Items	Components	
	1	2
1.1 We develop SSCS practices		,735
1.2 Each one spontaneously undertake SSCS for its own needs		,807
1.3 SSCS is a formalized process	,823	
1.4 SSCS relies upon information systems	**,866**	
1.5 SSCS forms part of some employees' mission	*,474*	*,423*
1.6 SSCS is undertaken by departments for their own needs		,744
1.7 We initiate SSCS in relation with projects		**,878**
1.8 SSCS takes place within general or functional management		,685
1.9 A SSCS structural entity exists	,663	
1.10 We use information providers to operate SSCS	,790	
1.11 SSCS information formally circulate	,817	

Nota*: As it is correlated on all components, item 1.5 has not been captured by the analysis.*

Cluster analysis (Table 3) shows higher representation of the opportunistic dimension of the organization of SSCS. For the three groups identified, the opportunistic component is higher that the formal one, confirming the absence of VLD structuration, even for the more committed respondents.

Table 3. Final groups centers (means) from organization of SSCS Cluster Analysis

	Means by cluster		
	1	2	3
« opportunistic organization»	**3,43**	**1,77**	**4,05**
« formal organization»	2,14	1,27	3,61

4.2. SSCS scope: themes monitored

Table 4 presents the results of the descriptive analysis concerning the themes monitored in SSCS. Legislation/rules (item 2.3) is the main theme monitored by all the respondents. Nevertheless, the other themes proposed appear to be considered as important too. We note a slight focus on downstream supply chain themes (items 2.1 and 2.5 for example) and specific attention on 'strategic movements of external actors' (item 2.2), and 'other organizations' sustainable logistics practices' (item 2.12). In line with these first results, respondents grant importance to the 'opportunities of collaborative logistics practices' (item 2.14) and to the 'sustainable logistics business opportunities' (item 2.4).

Table 4. Frequencies, means and standard deviations of themes monitored

	2 – Please indicate if the monitoring of the proposed THEMES is important or not for the SSCS practices of your organization							
	Frequencies					Mean	Std deviation	Std error
	I strongly disagree				I strongly agree			
2.3 Legislation/rules concerning sustainable development or SSCM	4 (3,2%)	2 (1,6%)	13 (10,3%)	40 (31,7%)	67 (53,2%)	4,3	0,949	,085
2.1 Market evolutions	6 (4,8%)	2 (1,6%)	20 (15,9%)	52 (41,3%)	46 (36,5%)	4,03	1,011	,090
2.21 Ways to reduce energy consumption	5 (4%)	3 (2,4%)	27 (21,4%)	40 (31,7%)	51 (40,5%)	4,02	1,039	,093
2.17 Logistics organization and frameworks	6 (4,8%)	9 (7,1%)	13 (10,3%)	53 (42,1%)	45 (35,7%)	3,97	1,088	,097
2.5 Clients' products and services needs concerning sustainable development or SSCM	5 (4,0%)	5 (4,0%)	22 (17,5%)	56 (44,4%)	38 (30,2%)	3,93	0,997	,089
2.24 Waste management	4 (3,2%)	10 (7,9%)	23 (18,3%)	43 (34,1%)	46 (36,5%)	3,93	1,075	,096
2.29 Safety for supply chains workers	8 (6,3%)	11 (8,7%)	18 (14,3%)	36 (28,6%)	53 (42,1%)	3,91	1,22	,109
2.11 Sustainable logistics evaluation methods (for example carbon footprint)	5 (4,0%)	3 (2,4%)	26 (20,6%)	60 (47,6%)	32 (25,4%)	3,88	0,952	,085
2.26 Energy (prices, scarcity, new energies)	5 (4,0%)	15 (11,9%)	16 (12,7%)	44 (34,9%)	46 (36,5%)	3,88	1,15	,102
2.30 Occupational health in supply chains	7 (5,6%)	10 (7,9%)	26 (20,6%)	34 (27,0%)	49 (38,9%)	3,86	1,185	,106
2.31 Hardness at work in supply chains	5 (4,0%)	11 (8,7%)	25 (19,8%)	44 (34,9%)	41 (32,5%)	3,83	1,101	,098
2.14 Opportunities for collaborative logistics practices (e.g. pooling of transport and logistics resources)	9 (7,1%)	10 (7,9%)	19 (15,1%)	55 (43,7%)	33 (26,2%)	3,74	1,147	,102
2.2 Strategic movements of external actors	6 (4,8%)	10 (7,9%)	30 (23,8%)	54 (42,9%)	26 (20,6%)	3,67	1,043	,093
2.20 Green transport modes	7 (5,6%)	12 (9,5%)	27 (21,4%)	51 (40,5%)	29 (23%)	3,66	1,104	,098
2.22 Infrastructures projects for sustainable logistics	9 (7,1%)	9 (715%)	29 (23%)	49 (38,9%)	30 (23,8%)	3,65	1,134	,101
2.25 Means to reduce pollution	9 (7,1%)	11 (8,7%)	25 (19,8%)	51 (40,5%)	30 (23,8%)	3,65	1,148	,102
2.9 Sustainable logistics technologies	6 (4,8%)	14 (11,1%)	30 (23,8%)	46 (36,5%)	30 (23,8%)	3,63	1,107	,099
2.12 Other organizations' sustainable logistics practices	6 (4,8%)	8 (6,3%)	31 (24,6%)	62 (49,2%)	19 (15,1%)	3,63	0,977	,087
2.23 Transport multi-modality	11 (8,7%)	15 (11,9%)	20 (15,9%)	44 (34,9%)	36 (28,6%)	3,63	1,257	,112
2.4 Sustainable logistics business opportunities	7 (5,6%)	8 (6,3%)	39 (31,0%)	44 (34,9%)	28 (22,2%)	3,62	1,072	,096
2.13 Sustainable logistics news	9 (7,1%)	9 (7,1%)	28 (22,2%)	55 (43,7%)	25 (19,8%)	3,62	1,102	,098
2.7 Consumers' expectations evolutions concerning sustainable development or sustainable logistics	7 (5,6%)	9 (7,1%)	39 (31,0%)	44 (34,9%)	27 (21,4%)	3,6	1,075	,096
2.16 Social and environmental risk management methods	9 (7,1%)	14 (11,1%)	27 (21,4%)	51 (40,5%)	25 (19,8%)	3,55	1,143	,102
2.6 Voluntary norms and labels concerning sustainable development or sustainable logistics	8 (6,3%)	10 (7,9%)	36 (28,6%)	51 (40,5%)	21 (16,7%)	3,53	1,063	,095
2.28 Raw materials (prices, scarcity, new uses)	10 (7,9%)	18 (14,3%)	29 (23,0%)	35 (27,8%)	34 (27,0%)	3,52	1,25	,111
2.8 Financial assistance for sustainable logistics	7 (5,6%)	15 (11,9%)	37 (29,4%)	41 (32,5%)	26 (20,6%)	3,51	1,115	,099
2.15 Reverse logistics practices	12 (9,5%)	20 (15,9%)	25 (19,8%)	35 (27,8%)	34 (27,0%)	3,47	1,3	,116
2.10 Management practices to select providers with sustainable criteria	6 (4,8%)	21 (16,7%)	31 (24,6%)	54 (42,9%)	15 (14,1%)	3,39	1,043	,093
2.19 Urban goods transport	13 (10,3%)	25 (19,8%)	28 (22,2%)	32 (25,4%)	28 (22,2%)	3,29	1,297	,116
2.18 Urban mobility	14 (11,1%)	25 (19,8%)	32 (25,4%)	34 (27,0%)	21 (16,7%)	3,18	1,248	,111

2.27 Biodiversity related to supply chains	17 (13,5%)	29 (23,0%)	37 (29,4%)	34 (27,0%)	9 (7,1%)	2,91	1,153	,103

Nota1*: Results are presented following decreasing mean*

Nota2*: In the table, most important results are enhanced in colour.*

Table 5. Component matrix from themes monitored Component Analysis

Items	Components					
	1	2	3	4	5	6
2.1 Market evolutions	**,783**					
2.2 Strategic movements of external actors	,553					
2.3 Legislation/rules concerning sustainable development or SSCM						
2.4 Sustainable logistics business opportunities	,772					
2.5 Clients' products and services needs concerning sustainable development or SSCM	**,792**					
2.6 Voluntary norms and labels concerning sustainable development or sustainable logistics						
2.7 Consumers' expectations evolutions concerning sustainable development or sustainable logistics	,431					
2.8 Financial assistance for sustainable logistics			*,511*		*,412*	
2.9 Sustainable logistics technologies			,641			
2.10 Management pratices to select providers with sustainable criteria					,684	
2.11 Sustainable logistics évaluation methods (for example carbon footprint)					**,846**	
2.12 Other organizations' sustainable logistics practices	*,454*				*,441*	
2.13 Sustainable logistics news	,632					
2.14 Opportunities for collaborative logistics practices (e.g. pooling of transport and logistics resources)						**,741**
2.15 Reverse logistics practices	*,432*					*,482*
2.16 Social and environmental risk management methods		,687				
2.17 Logistics organization and frameworks	,488					
2.18 Urban mobility				**,968**		
2.19 Urban goods transport				**,956**		
2.20 Green transport modes				,732		
2.21 Ways to reduce energy consumption						
2.22 Infrastructures projects for sustainable logistics				,421		
2.23 Transport multi-modality						,633
2.24 Waste management		*,450*				*-,484*
2.25 Means to reduce pollution			,404			
2.26 Energy (prices, scarcity, new energies)			,745			
2.27 Biodiversity related to supply chains			,636			
2.28 Raw materials (prices, scarcity, new energies)			**,982**			
2.29 Safety for supply chains workers		**,952**				
2.30 Occupational health in supply chains		**,985**				
2.31 Hardness at work in supply chains		**1,013**				

Nota*: As they are correlated on more than one component or are low correlated, items in italics have not been captured by the analysis.*

PCA (Table 5) structures the themes monitored in six dimensions:

- '**Market trends**' (component 1) relying mainly on 'client's products and services needs' (0.792), 'market evolutions' (0.783), 'business opportunities' (0.772) and lower on 'sustainable logistics news' (0.632), 'external actors strategic movements' (0.553), 'logistics organization and frameworks' (0.488) and 'consumers' expectations evolutions concerning sustainable development or sustainable logistics' (0.431);
- '**Work hardness, health and security**' (component 2) relying on 'hardness at work in supply chains' (1.013), 'occupational health' (0.985), 'safety for supply chains workers' (0.952) and lower on 'social and environmental risk management methods' (0.687);

- ‘**Raw materials, energy, technologies**’ (component 3) relying mainly on ‘raw materials’ (0.982), ‘energy (prices, scarcity, new uses’ (0.745) and lower on ‘sustainable logistics technologies’ (0.641) and ‘means to reduce pollution’ (0.404);
- ‘**Transport and urban mobility**’ (component 4) relying mainly on ‘urban mobility’ (0.968), ‘urban goods transport’ (0.956) ‘green transport modes’ (0.732) and lower on ‘infrastructures projects for sustainable logistics’ (0.421);
- ‘**Benchmark and best practices**’ (component 5) relying on ‘sustainable logistics evaluation methods’ (0.846) and lower on ‘management practices to select providers with sustainable criteria’ (0.684);
- ‘**Collaborative practices**’ (component 6) relying on ‘opportunities for collaborative logistics practices’ (0.761) and lower on ‘multimodality’ (0.633).

Surprisingly, items 2.3 ‘legislation/rules concerning sustainable development or sustainable logistics’ (the major theme according to the respondents) and 2.6 ‘voluntary norms and labels’ do not appear in the dimensions probably because items in relation to those thematics are not numerous enough.

Cluster analysis (Table 6) shows that the themes monitored do not allow drawing up a differentiation between groups’ practices. Even if the categories of themes are not prioritized in the same way, each category of themes appears to be as important as the other. Concerning the themes approach, the delineation of SSCS scope thus appears to be very broad.

Table 6. Final groups centers (means) from themes monitored Cluster Analysis

	Means by cluster	
	1	2
« Market trends»	3,97	2,97
« Hardness, health, safety»	4,13	2,84
« Raw materials, energy and technologies»	3,83	2,57
« Urban transport and mobility»	3,76	2,48
« Benchmark and best practices »	3,84	2,87
« Collaborative practices»	4,00	2,75

4.3 SSCS scope: actors monitored

Table 7 presents the result of the descriptive analysis concerning the actors monitored in SSCS. Firstly we must note that means and consensus degree obtained in the analysis of actors monitored are lower than means and consensus degree for themes monitoring. Next research could compare these results through Student’s tests to show off that SSCS targeting practices mainly rely on themes approach.

Concerning the monitoring of actors, one appears to be dominant: the client (item 3.1). Other actors (competitors, item 3.3; providers, item 3.5; territorial institutions, item 3.13) and many others are considered as important to monitor. Here again, the scope definition of SSCS is very broad. Some other elements (clusters, item 3.17, specific providers, items 3.10, 3.9, 3.6) are considered as less important probably because they do not directly concern all respondents.

Table 7. Frequencies, means and standard deviations of actors monitored

	3- Please indicate if the monitoring of the proposed ACTORS is important or not for the SSCS practices of your organization							
	Frequencies					Mean	Std deviation	Std error
	I strongly disagree				I strongly agree			
3.1 Our direct clients	7 (5,6%)	4 (3,2%)	14 (11,1%)	33 (26,2%)	68 (54,0%)	4,2	1,117	,100
3.19 Leading sustainable logistics actors	9 (7,1%)	10 (7,9%)	31 (24,6%)	45 (35,7%)	31 (24,6%)	3,63	1,151	,102
3.3 Our competitors	12 (9,5%)	10 (7,9%)	22 (17,5%)	52 (41,3%)	30 (23,8%)	3,62	1,206	,107
3.14 Certifications' institutes	10 (7,9%)	12 (9,5%)	24 (19,0%)	53 (42,1%)	27 (21,4%)	3,6	1,161	,103
3.13 Territorial institutions	11 (8,7%)	14 (11,1%)	26 (20,6%)	45 (35,7%)	30 (23,8%)	3,55	1,217	,108
3.5 Our providers	11 (8,7%)	14 (11,1%)	27 (21,4%)	47 (37,3%)	27 (21,4%)	3,52	1,198	,107
3.8 Our logistics service players	14 (11,1%)	11 (8,7%)	30 (23,8%)	44 (34,9%)	27 (21,4%)	3,47	1,237	,110
3.4 Our waste management providers	11 (8,7%)	16 (12,7%)	28 (22,2%)	47 (37,3%)	24 (19,0%)	3,45	1,191	,106
3.2 Clients of our clients	13 (10,3%)	16 (12,7%)	29 (23,0%)	41 (32,5%)	27 (21,4%)	3,42	1,248	,111
3.15 Infrastructures management firms (ports, airports…)	15 (11,9%)	14 (11,1%)	30 (23,8%)	41 (32,5%)	26 (20,6%)	3,39	1,265	,113
3.11 Our other providers (energy, motors, etc.)	15 (11,9%)	16 (12,7%)	29 (23,0%)	47 (37,3%)	19 (15,1%)	3,31	1,223	,109
3.23 Consumers	22 (17,5%)	11 (8,7%)	26 (20,6%)	44 (34,9%)	23 (18,3%)	3,28	1,342	,120
3.18 Professional associations and unions	17 (13,5%)	19 (15,1%)	27 (21,4%)	44 (34,9%)	19 (15,1%)	3,23	1,266	,113
3.7 Our industrial subcontractors	16 (12,7%)	21 (16,7%)	35 (27,8%)	35 (27,8%)	19 (15,1%)	3,16	1,242	,111
3.24 Citizens	20 (15,9%)	18 (14,3%)	29 (23,0%)	40 (31,7%)	19 (15,1%)	3,16	1,299	,116
3.25 Media	17 (13,5%)	19 (15,1%)	33 (26,2%)	43 (34,1%)	14 (11,1%)	3,14	1,211	,108
3.16 Board of trade and other consular entities	15 (11,9%)	19 (15,1%)	45 (35,7%)	33 (26,2%)	14 (11,1%)	3,1	1,155	,103
3.12 Our shareholders	26 (20,6%)	16 (12,7%)	32 (25,4%)	30 (23,8%)	22 (17,5%)	3,05	1,379	,123
3.17 Competitivity poles and clusters	18 (14,3%)	20 (15,9%)	47 (37,3%)	27 (21,4%)	14 (11,1%)	2,99	1,183	,105
3.6 Providers of our providers	23 (18,3%)	32 (25,4%)	29 (23,0%)	31 (24,6%)	11 (8,7%)	2,8	1,246	,111
3.20 Associations	20 (15,9%)	30 (23,8%)	43 (34,1%)	28 (22,2%)	5 (4,0%)	2,75	1,095	,098
3.22 Labour unions	27 (21,4%)	30 (23,8%)	30 (23,8%)	29 (23,0%)	10 (7,9%)	2,72	1,256	,112
3.10 Our engineering providers (consultants)	31 (24,6%)	23 (18,3%)	35 (27,8%)	28 (22,2%)	9 (7,1%)	2,69	1,262	,112
3.9 Our information systems providers	31 (24,6%)	24 (19,0%)	35 (27,8%)	27 (21,4%)	9 (7,1%)	2,67	1,257	,112
3.21 NGOs	29 (23,0%)	27 (21,4%)	45 (35,7%)	19 (15,1%)	6 (4,8%)	2,57	1,141	,102

Nota1*: Results are presented following decreasing mean.*

Nota2*: In the table, most important results are enhanced in colour.*

PCA (Table 8) structures the actors monitored in five dimensions:

- '**Providers**' (component 1) relying mainly on 'our providers' (0.908), 'our waste management providers' (0.853), 'providers of our providers' (0.780), 'our industrial subcontractors' (0.780) and lower on 'our other providers' (0.643) and 'our logistics service players' (0.604);
- '**Associations, unions and NGOs**' (component 2) relying on a huge diversity of heterogeneous actors 'NGOs' (0.932), 'diverse associations' (0.807) and lower on 'our

engineering providers' (0.696), 'labour unions' (0.680), 'professional associations and unions' (0.650), 'competitivity poles and clusters' (0.590). We can note that this component federates network organisations favouring cross-fertilization;

- '**Developer contractors**' (component 3) relying on 'territorial institutions' (0.833) and lower on 'infrastructures management firms' (0.647);
- '**Clients and competitors**' (component 4) relying on 'our direct clients' (0.929), clients of our clients' (0.769), and 'our competitors' (0.736);
- '**Civil society**' (component 5) relying on 'citizens (0.808), 'consumers' (0.737) and lower on 'media' (0.620).

Table 8. Component matrix from actors monitored Component Analysis

Items	Components				
	1	2	3	4	5
3.1 Our direct clients				**,929**	
3.2 Clients of our clients				,769	
3.3 Our competitors				,736	
3.4 Our waste management providers	,853				
3.5 0ur providers	**,908**				
3.6 Providers of our providers	,780				
3.7 Our industrial subcontractors	,780				
3.8 Our logistics service players	,604				
3.9 Our information systems providers	*,405*	*,649*			
3.10 Our engineering providers (consultants)		,696			
3.11 Our other providers (energy, motors…)	,643				
3.12 Our shareholders	*,413*	*,413*			
3.13 Territorial institutions			**,833**		
3.14 Certifications' institutes	*,557*		*,679*		
3.15 Infrastructure management firms (ports, airports)			,647		
3.16 Board of trade and other consular entity		*,460*	*,648*		
3.17 Competitivity poles and clusters		,590			
3.18 Professional associations and unions		,650			
3.19 Leading sustainable logistics actors			*,406*		
3.20 Diverse associations		,807			
3.21 NGOs		**,932**			
3.22 Labour unions		,680			
3.23 Consumers					,737
3.24 Citizens					**,808**
3.25 Media					,620

***Nota**: As they are correlated on more than one component or are low correlated, items in italics have not been captured by the analysis.*

Cluster analysis (Table 9) reveals the existence of two groups reflecting two intensities of actors monitoring. For each group, the 'clients and competitors' component is the most important probably traducing a restrictive vision of the supply chain. Like in the previous section, the monitoring of actors does not allow to differentiate between firms.

Table 9. Final groups centers (means) from actors monitored Cluster Analysis

	Mean by cluster	
	1	2
« providers»	3,66	2,30
« associations, unions and NGOs»	3,33	1,86
« development contractors »	3,78	2,59
« clients and competitors»	**4,13**	**2,92**
« civil society»	3,79	1,92

4.4 SSCS practices

Finally, an exploratory cluster analysis federating the whole results of SSCS depiction has been realized (Table 10).

Table 10. Final groups centers (means) from SSCS practices Cluster Analysis

Components	**Clusters**	
	1	**2**
Organization/ « **opportunistic organization**»	3,59	2,50
Organization/ **« formal organization»**	**2,78**	**1,81**
Themes/« **Market trends**»	4,01	3,18
Themes/ **« Hardness, health, safety»**	4,13	3,20
Themes/ « **Raw materials, energy, technologies**»	3,83	2,92
Themes/ « **Urban transport and mobility**»	3,83	2,71
Themes/ « **Benchmark and best practices** »	3,89	3,04
Themes/ « **Collaborative practices**»	4,02	3,06
Actors/« **Providers**»	3,65	2,40
Actors/ «**Associations, unions and NGOs**»	3,37	1,88
Actors/ « **Infrastructure developers** »	3,85	2,55
Actors/ « **Clients and competitors**»	4,11	3,05

The final cluster analysis above shows evidence of two groups of respondents, the second one being smaller (34,1% of the respondents) than the first one (65,9%). Group 1 federates respondents which level of SSCS organization and themes/actors monitoring can be considered as average even if the formalization level of SSCS practices remains low. Group 2 presents SSCS practices even less formalized and showing off a lower monitoring of the sustainable environment. Cluster analysis does not show off any secant group attesting a high level of SSCS commitment.

5. Contribution

Our main contribution is to depict SSCS practices related to organization and scanning scope and provide new insights into how firms scan their environment with sustainable concern for their supply chains. French companies try to prepare their supply chains to face sustainable issues, but their SSCS practices are rather emerging. Overall, when it exists, SSCS is informal, opportunistic and latent. SSCS practices seem to be due to standalone managers' initiatives developing SSCS related to their own job and missions, on a temporary and adhoc basis. SSCS definitively do not appear as a collective, transversal and strategic activity. Nevertheless, factor analyses identify several components (see section 4) reflecting the SSCS emergence within French firms.

From a *managerial* perspective, the broad scanning scope, without clear prioritization (unsurprisingly pointing up legislation aspects, probably illustrating the reactive dimension of sustainable logistics), suggests that companies don't really know how to structure their scanning and shows off the necessity to develop scanning scope frameworks in order to guide the delineation of the external elements to be monitored. It perhaps also reveals that most companies have no clear SSCM strategy. This is of concern if we admit that sustainable issues call for a long-term vision of future supply chains. Results also prove that SSCM calls for a systemic understanding of the interdependencies between multiple interrelated factors. From a *theoretical* perspective, our research highlights interfaces between environmental scanning, sustainable development and SCM research areas, disconnected so far. Our exploratory study of French firms' SSCS practices does not completely renew ES but emphasizes the individual dimension of scanning and shows off the need to adopt a broad and systemic approach of the scanning scope. From a *methodological* perspective, it is a first step on measure scales validation on scanning practices in a SSCM context.

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References

Adema, K.L. and Roehl, W.S. (2010). Environmental scanning the future of event design, *International Journal of Hospitality Management*, 29/2, 199-207.

Aaker, D.A. (1983). Organizing a strategic information scanning system, *California Management Review*, 25/2, 76-83.

Aguilar, F. J (1967). *Scanning the business environment*, New-York, Macmillan.

Asif, M., Searcy, C., Zutshi, A. and Niaz, A. (2011). An integrated management systems approach to corporate sustainability, *European Business Review,* 23/4, 353-367.

Badri, M. A., Davis, D. and Davis, D. (2000). Operations strategy, environmental uncertainty and performance: a path analytic model of industries in developing countries, *Omega*, 28/2, 155-173.

Bates, C.S. (1985). Mapping the environment: an operational environmental analysis model, *Long Range Planning*, 18/5, 97-105.

Beske, P., Koplin, J. and Seuring, S., (2008). The use of environmental and social standards by German first-tier suppliers of the Volkswagen AG, *Corporate Social - Responsibility and Environmental Management,* 15/2, 63-75.

Braunscheidel, M. J. and Suresh, N. C. (2009). The organizational antecedents of a firm's supply chain agility for risk mitigation and response, *Journal of Operations Management*, 27/2, 119-140.

Calori, R. (1989). Designing a business scanning system, *Long Range Planning*, 22/1, 69-82.

Carter, C.R. and Rogers, D.S. (2008). A framework of sustainable supply chain management: moving towards new theory, *International Journal of Physical Distribution & Logistics Management*, 38/5, 360-87.

Carter, R.C. and Easton, P.L. (2011). Sustainable supply chain management: evolution and futures directions, *International Journal of Physical Distribution and Logistics Management*, 41/1, 46-62.
Choi, T. and Kim, Y. (2008). Structural embeddedness and supplier management: a network perspective, *Journal of Supply Chain Management*, 44/4, 5-13.
Clemens, R. (2009). Environmental Scanning and Scenario Planning: A 12 month Perspective on Applying the Viable Systems Model to Developing Public Sector Foresight, *Systemic Practice and Action Research,* 22/ 4, 249-274.
Elkington, J. (1997), *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*, Capstone, Oxford.
Etzioni, A. (1967). Mixed scanning: A 'third' approach to decision making, *Public Administration Review*, 27/ 5, 385-392.
Fabbe-Costes, N., Roussat, C. and Colin, J. (2011a). Future sustainable supply chains: what should companies scan in their environment?, *International Journal of Physical Distribution and Logistics Management*, 41/3, 228-252.
Fabbe-Costes, N., Roussat, C. and Colin, J. (2011b). Targeting "sustainable scanning": a methodology based on logistcs and supply chain management. In N. Lesca (ed.), *Strategic scanning and sustainable development*, ISTE Ldt, London & John Wiley and Sons Inc, London, 185-212.
Fabbe-Costes, N. (coord.) (2011c). *Etat des lieux des pratiques de « veille logistique durable » : une approche qualitative*, Rapport scientifique d'étape VLD.1 – PREDIT 4 – ADEME, Septembre.
Fahey, L. and King, W.H. (1977). Environmental Scanning for Corporate Planning, *Business Horizons*, 20/4, 61-71.
Fahey, L. King, W.H. and Narayanan, V.K. (1981). Environmental Scanning and Forecasting in Strategic Planning: the State of the Art, *Long Range Planning*, 14/1, 32-39.
Gold, S., Seuring, S. and Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: a literature review, *Corporate Social - Responsibility and Environmental Management,* 17/4, 230-245.
Hair, J., Anderson, R., Tatham, R., and Black, W. (1998). *Multivariate data analysis* (5e ed.). New Jersey : Prentice-Hal.
Hambrick, D.C. (1982). Environmental Scanning and Organizational Strategy, *Strategic Management Journal,* 3/ 2, 159-159.
Herring, J.P. (1988). Building a business intelligence system, *Journal of Business Strategy*, 9/3, 4-9.
Harland, C., Brenchley, R. and Walker, H. (2003). Risk in supply network, *Journal of Purchasing & Supply Management*, 9/2, 51-62.
Holmberg, S.L. and Cummings, J.L. (2009). Building successful strategic alliances, *Long Range Planning*, 42/2, 164-193.
Jain, S.C. (1984). Environmental scanning in US corporations, *Long Range Planning*, 17/2, 117-128.
Jamail, D. and Mirshak, R. (2007). Corporate Social Responsibility (CSR): Theory and Practice in a Developing Country Context, *Journal of Business Ethics,* 72/ 3, 243-262.
Jayaraman, V., Klassen, R. and Linton, J. D. (2007). Supply chain management in a sustainable environment, *Journal of Operations Management*, 25/ 6, 1071-1074.
Kelly, R., Sirr, L. and Ratcliffe, J. (2004). Futures thinking to achieve sustainable development at local level in Ireland, *Foresight*, 6/ 2, 80-90.
Klassen, R.D. and Vereecke, A. (2012). Social issues in supply chains: Capabilities link responsibility, risk (opportunity), and performance, *International Journal of Production Economics*, 140/1, 103-115.

Kleindorfer, P.R., Singhal, K. and van Wassenhove, L.N. (2005). Sustainable Operations Management, *Production and Operations Management*, 14/4, 482-492.

Koufteros, X., Vickery, S., and Dröge, C. (2012). The effects of strategic supplier selection on buyer competitive performance in matched domains: does supplier integration mediate the relationships?, *Journal of Supply Chain Management,* 48/2, 93-115.

Kovács, G. (2008). Corporate environmental responsibility in the supply chain, *Journal of Cleaner Production*, 16/15, 1571-1578.

Krause, D. R., Vachon, S. and Klassen, R.D. (2009). Special Topic Forum on Sustainable Supply Chain Management: Introduction and Reflections on the Role of Purchasing Management, *Journal of Supply Chain Management,* 45/ 4, 18-25.

Kristal, M. M., Huang, X., and Roth, A. V. (2010). The effect of an ambidextrous supply chain strategy on combinative competitive capabilities and business performance, *Journal of Operations Management*, 28/ 5, 415-429.

Lenz, R.T. and Engledow, J.L. (1986). Environmental analysis units and strategic decision-making: a field study of selected "leading edge" coporations, *Strategic Management Journal*, 7/1, 69-89.

Lesca, N., Caron-Fasan, M-L. and Falcy, S. (2012). How managers interpret scanning information, *Information and Management*, 49/ 2, 126-134.

March, S. T. and Hevner, A. R. (2007). Integrated decision support systems: A data warehousing perspective, *Decision Support Systems*, 43/ 3, 1031-1043.

Markley, M. J. and Davis, L. (2007). Exploring future competitive advantage through sustainable supply chains, *International Journal of Physical Distribution & Logistics Management,* 37/ 9, 763-774.

Mendonça, S., Cunha, M. P. E., Kaivo-Oja, J. and Ruff, F. (2004). Wild cards, weak signals and organisational improvisation, *Futures,* 36/2, 201-218.

Ngamkroeckjoti, C. and Johri, L.M. (2000). Management of environmental scanning processes in large companies in Thailand, *Business Process Management Journal,* 6/4, 331-331.

Oreja-Rodriguez, J., R. and Yanes-Estevez, V. (2007). Perceived environmental uncertainty in tourism: a new approach using the Rasch model, *Tourism Management*, 28/6, 1450-1463.

Pagell, M. and Wu, Z. (2009). Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars, *Journal of Supply Chain Management,* 45/2, 37-56.

Preble, J.F. Rau, P.A. and Reichel, A. (1988). The environmental scanning practices of US multinationals in the late 1980s, *Management International Review*, 28/4, 4-14.

Rao, P. and Holt, D. (2005). Do green supply chains lead to competitiveness and economic performance?, *International Journal of Operations and Production Management*, 25/9, 898–916.

Roberts, S. (2003). Supply chain specific? Understanding the patchy success of ethical sourcing initiatives, *Journal of Business Ethics*, 44/2-3, 159-70.

Roussat, C. (1996). *Organisation de la surveillance de l'environnement dans les entreprises françaises*, Thèse pour le doctorat en sciences de gestion, Université Aix-Marseille III, IAE, France.

Schlange, L. E. (2006). Stakeholder Identification in Sustainability Entrepreneurship, *Greener Management International*, 55, 13-32.

Seuring, S. and Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management, *Journal of Cleaner Production*, 16/15, 1699-1710.

Slaughter, R.A., (1999). A new Framework for environmental scanning, *Foresight*, 1/15, 441-451.

Srinavasan, M., Mukherjee, D., and Gaur, A.S. (2011). Buyer-supplier partnership quality and supply chain perfomance: Moderating role of risks and environmental uncertainty, E*uropean Management Journal*, 29/4, 260-271.
Stoffels, J.D. (1982). Environmental scanning for future success, *Managerial Planning*, 3/3, 4-12.
Stubbart, C.I. (1982). Are Environmental Scanning Units Effective? , *Long Range Planning,* 15/3, 139-145.
Subramanian, R., Fernandes, N. and Harper, E. (1993). Environmental scanning in U.S. companies: their nature and their relationship to performance, *Management International Review*, 33/3, 276-286.
Tilley, F. and Fuller, T. (2000). Foresighting methods and their role in researching small firms and sustainability, *Futures,* 32/2, 149-161.
Tonn, B. (2008). A methodology for organizing and quantifying the results of environmental scanning exercises, *Technological Forecasting and Social Change*, 75/5, 595-609.
Voros, J. (2001). Reframing environmental scanning: an integral approach, *Foresight*, 3/6, 533-52.
Voros, J. (2003). A generic foresight process framework, *Foresight*, 5/3, 10-21.
Will, M. (2008). Talking about the future within an SME?, *Management of Environmental Quality,* 19/2, 234-242.
Wolf, J. (2011). Sustainable Supply Chain Management Integration: A Qualitative Analysis of the German Manufacturing Industry, *Journal of Business Ethics,* 102/2, 221-235.
Wong, H.Y. and Hung, J-Y. (2012). Environmental scanning literature – past, present and future research propositions, *International Journal of Business Environment,* 5/1, 30-50.
Xu, M.X., Kaye, G.R. and Duan, Y. (2003). UK executives ' vision on business environment for information scanning. A cross industry study, *Information & Management,* 40/5, 381-389.
Zhu, Q., J. Sarkis and K. Lai. (2008). Confirmation of a Measurement Model for Green Supply Chain Management Practices and Implementation, *International Journal of Production Economics*, 111/2, 261-273.

Connecting to Resources: Analogies Between Dark Networks and Industrial Systems

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Although detailed empirical work on the structure of industrial supply chains is in its infancy, there is an extensive literature on the morphology and praxis of criminal and terrorist 'dark networks'. There are a surprising number of parallels in the empirical challenges presented by both domains: networks are rarely static; participants have incentives to withhold information to outsiders; and, crucially, participants in the networks themselves may be ignorant of the detail of the web in which they operate. We present a review of recent work on terrorist and criminal networks and develop a series of comparisons with conventional supply networks, focussing on questions of information flow, resilience and network epistemology. We emphasise the way in which the distribution of products, expertise and capabilities characterise the network, illustrating a simple mathematical procedure for describing actors' ease of access to such resources.

Keywords: *Supply Network Structure, Dark Networks, Supply Chain Mapping.*

Introduction

> "'What he's talking about here isn't a map, it's a link chart,' Matlock complains, in the tone of a man correcting Dima's inadequate vocabulary. 'And I'll just say this regarding link charts, if you'll bear with me. I've seen a few link charts in my time. They tend to resemble multicoloured rolls of barbed wire leading in no direction know to man, in my experience. Useless, in other words, in my judgement.'"
>
> (Le Carré, "Our Kind of Traitor", 2010: 154-155).

> "I want targets. Do your f****** jobs, bring me people to kill."
>
> (Boal, "Zero Dark Thirty" 2011: 52).

In this paper we develop a way of thinking about 'dark networks' – networks associated with crime and terrorism – inspired by our work on conventional industrial supply networks. Recent years have seen an extensive growth in the literature surrounding dark networks. In parallel, understanding firms' supply chains has become both a key issue for business research, and a central issue for corporations. It is widely understood that firms do not compete as atomistic islands of activity, but in complex webs of other organisations: firms' fates are tied up with those of their supply chain partners. Over a twenty-year period, this idea has achieved central prominence in business: should firms make or buy? Should they form a small number of key and stable relationships, or should they use the power of the market to adaptively draw on a wide pool of suppliers? Should they seek to manage the firms several stages down the chain from them?

These questions have prompted a wide range of analyses, including the Nobel Prize winning microeconomics of Ronald Coase and Oliver Williamson. Academics from a wide range of disciplines, including Operations Management, Marketing, Management Science, Network Science, Strategy, Reputation Management, Corporate Social Responsibility and Accounting have explored these issues. However, it has been noted by many researchers that progress in the field has frequently been limited by the lack of robust and detailed accounts of what supply chains actually look like. For although the evidential base of supply chain management is very substantial, much of the work describes only fragments of chains, or rests on the analysis of idealized models which do not reflect empirical reality. The problem is that it is very difficult to draw convincing maps of supply chains/networks – to plot out who supplies whom.

There are three main reasons why this has been so. First, it is intrinsically difficult to handle the complexity of the data. Although conceptually supply chains are pretty simple, once one gets into the messy reality one finds that one may be dealing with a shifting picture in which thousands of suppliers provide thousands of products. Second, in many cases much of the data is distributed – no-one person knows what the big picture looks like, and so the map must be assembled from sometimes fragmentary and inconsistent data. Third, the data is itself sometimes commercially confidential. Despite these obstacles, recent years have seen the emergence of several studies that have made progress in these areas: the general issue has been discussed by, among others, Nassimbeni (2004); Battini et al (2007), Borgatti and Li (2009), Bellamy and Basole (2013). Specific empirical studies have shown partial supply chain maps, especially in the automotive industry (Choi and Hong 2002; Choi and Wu 2009; Brintrup et al 2011; Kito et al 2011).

Mapping Dark Networks

The idea of 'dark network' analysis is well-established in the literature, especially since the 9/11 attacks and the emergence of Al-Qaeda (Krebs 2002; Raab and Milward 2003; Roberts and Everton 2011; Perliger and Pedahzur 2011; Miklaucic and Brewer 2013). This new work has largely built on previous research on organised crime and other terrorist groups (e.g. Sparrow 1991; Baker and Faulkner 1993; McIllwain 1999). It has been boosted by large amounts of funding stimulated by the 'War on Terror', efforts in respect of counter-insurgent activity in Iraq and Afghanistan: Weinberger (2011) reports an estimate of spending by the US Office of the Secretary of Defense of $28m in related research and development in 2011 alone. It has also benefited from developments in network science (especially the development of mapping software). An extensive discussion of this work is presented in the recent (2012) authoritative monograph by Sean Everton "Disrupting Dark Networks". Terrorism is – in Jason Burke's (2013) words – "*a social activity like any other*."

Within this now extensive body of literature, it is fair to say that there is relatively little which reflects ideas from supply chain research. Few papers make any connection to the supply chain/supply network literature, and the dominant mode of analysis has been to consider *undirected* networks with the emphasis on 'connections' (e.g. Harris-Hogan 2013). This emphasis on the morphology of the network has led to a variety of tools and approaches based on understanding the structure of interlinkages between actors. Xu and Chen (2008) make observations, for example, about path length, clustering coefficients and degree distributions (i.e. the distribution of links among nodes) of three contrasting networks. Some of this work has sought to bring general network insights into the operation of these groups, but by far the dominant research paradigm is the use of the analysis to identify 'key players', with the implicit or explicit purpose that these might be 'taken out' to undermine the operation of the network: Morganthaler and Giles-Summers (2011:1) characterise this thinking as '*…the logic that by catching the right hornet, the whole colony dies*.'

This so-called 'kinetic' approach to network degradation has led to the development of a wide variety of measures of centrality in the network. For example, motivated by the limitations of existing measures, Qi et al (2013) develop a centrality metric based on Laplacian energy. Another issue is that some of the analytical methods adopted from network theory are computationally expensive - Michalak et al (2013), for example, focus on the computational efficiency of the analytic techniques, identifying the key players in a network of 36 members and 125 links in less than 40 minutes. Ovelgönne et al (2012) examine the problem in which key players in a dark network may actively seek to reduce their centrality given they are aware that the network is being monitored and analysed.

This general thrust in the literature – using network morphology to find the key players and then working out how the network is degraded if they are removed – has an undeniable intuitive appeal, and presents a host of interesting analytical challenges (Borgatti 2006; Hoyer and De Jaegher 2010; McBride and Hewitt 2012; Shen et al 2013). Unfortunately, it also has some profound limitations, and may even be dysfunctional as a general strategy. To understand why, it is important to understand four limitations of the approach.

The first is that although it is convenient to lump 'dark networks' together as a single category, there may be substantial differences in the character and composition of such networks. Indeed, for some types of network, the paradigm of the organisation may be inappropriate. Early studies of criminal groups tended to emphasise the similarity of between them and formal organisations, including the use of technical jargon (Maurer 1955) and formal roles with titles and responsibilities (Spergel 1964). In particular, studies of organised crime groups such as the Mafia focussed on the need to understanding their sometimes rather rigid, hierarchical and stable network structures. This leads naturally to the idea that dealing with the key players in the network may significantly erode network capability.

However, in contrast, many terrorist 'organisations' have a far more fluid and disorganised structure, and the application of analysis (and counter-measures) that fails to recognise this has been criticised as by Sageman (2008) as "*muddled thinking and erroneous analysis*". He states:

> "All too often, when referring to it as a social movement, experts speak of the success or failure of al Qaeda's strategy, tactics, leadership, membership, recruitment, and division of labour (operators, communicators, financiers, supporters, logisticians). But these terms apply only to formal organizations with a coherent command and control structure, not to the informal groups of wannabes, copycats, or homegrown initiates who comprise the majority of the social movement." (31).

He goes on to characterise the 'nodes' in the network as "*…not members but participants*". The implication of this is that the structures are likely to be less stable, and actions less predictable: dismantling a 'command and control' structure is impossible, because it does not exist in the first place (Sageman 2004). Indeed, some writers have gone so far as to make rather sweeping generalisations to differentiate criminal and terrorist groups (e.g. Morselli et al 2007 assert, without support, that '*Terrorist networks lack a core, whereas criminal enterprises networks…are built outward from a core*'), but this is to overstate the distinction, as some have argued that even formally organised criminal operations have learned from the example of terrorist groups: Brzezinski (2002) describes international narcotics gangs adopting the '*Osama Bin Laden approach to management*' – emphasising remoteness of control, geographic dispersion and the use of 'sub-contractors'. The point is that is a wide range of structures and levels of formality, and considerable scope for adaptation (Everton and Cunningham 2013; Bright and Delaney 2013).

The second limitation is that because networks are highly dynamic and adaptable, the effect of ‘taking out’ a node may be very short-lived, as the network rapidly reconfigures in potentially unpredictable ways (ACC 2011; Bouchard and Amirault 2013). This is a well-understood problem – for example, described in the fictional account of Baltimore drugs trade in *The Wire* – but there are strong political reasons why ‘taking out the bad guys’ remains a fixture in crime fighting and counter-terrorism. In the fictional adaptation of the hunt for and eventual killing of Osama Bin Laden, screenwriter Mark Boal has a senior CIA officer demanding that the analysts bring him ‘people to kill’ – despite the clear evidence at the time that the attempts to ‘decapitate’ the network were having little affect on the Al-Qaeda network. More recently, the efficacy of this approach in respect of the current US programmes of drone strikes against international targets is strongly contested (see Cobain 2013). Not only do networks adapt to fill the void, but the process may generate complex sociological consequences (for example, the creation of ‘martyrs’) that make the situation worse (Morganthaler and Giles-Summers 2011). Additionally, given the epistemological difficulties of analysis, and the practical difficulties of execution (perhaps in the literal sense), it is easy for a node-elimination strategy to go wrong, killing or arresting innocent parties. Finally, node elimination may be expensive and dangerous.

The third limitation relates to the construction of the network which conventionally posits ‘nodes’ as individuals and the links between them as relationships: this is the approach adopted by Krebs (2002) in his influential study of the 9/11 attack, and has framed the way the field has evolved. This approach prioritizes the significance of people, and shifts the focus away from other material or informational assets which may have importance in understanding the operation of the networks.

A fourth limitation is one that affects all approaches to apply rigorous analysis to complex human problems: network approaches can never capture the whole picture of what is known about the situation. This issue is well-documented in a wide range of fields, and leads to the conclusion that formal techniques play a role in complementing broader analysis, which might include intuition and other difficult-to-encode data. In Operations Research, for example, it is well-established that for many problems what are needed are models which provide insight rather than calculations which provide rigorous answers (Simon 1990; Hurrion 1986). This particularly applies in situations in which data is incomplete or partially unreliable, constraints which are particularly relevant to the case of dark networks.

These arguments do not mean that kinetic approaches to network disruption are always wrong; but is does mean that in many cases they are impractical. Sageman (2008) comments that if network hubs are to be targeted, it might be necessary to tackle large numbers of them simultaneously. In the light of these difficulties, it is sensible to explore other styles of analysis which might contribute to the understanding of and response to dark networks.

An Alternative Approach

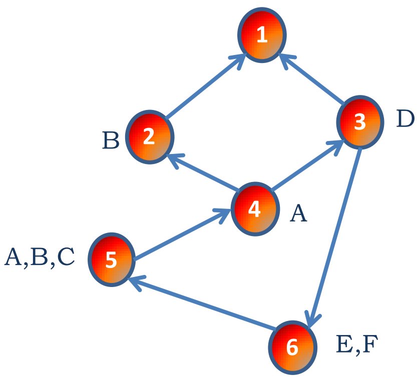
In the light of some of the points raised above, Carley (2006:55) states that ‘…what is needed is a dynamic network approach where there are multiple interlinked networks: i.e. a metanetwork linking various entities such as people, resources, knowledge, tasks and so on.’ The approach presented here departs from the general pattern of earlier work in that the network is defined by not just the linkages between nodes, but also by the distribution of resources and capabilities across these nodes (i.e., in Carley's terms, a metanetwork). We also focus on directed networks, with the assumption that in order to achieve its aims, the network exists to transmit resources to a final actor. The base paradigm which this abstraction represents is that of a cell of actors supporting the deployment of an Improvised Explosive Device (or IED). Sitting at the 'top' of the network, the 'bomber' is analogous to the Original Equipment Manufacturer sitting at the apex of an industrial supply network – for example (drawing on our prior work), the Toyota Motor company. Just as Toyota needs to have access to the resources of its supply base, the 'bomber' needs to be supplied with a variety of 'resources' – which in the IED case might be expertise, material, equipment, finance, information, or ideological support (Milla et al 2013).

The use of the label 'resources' warrants some discussion at this point. Little of the extant dark network research explicitly addresses this issue; an exception is the work of Bakker et al (2012), who include technology, finance, weapons, but also more abstract concepts such as physical space and cyberspace. However, our approach specifically associates resources with nodes on the network, with the assumption that they can be in some sense 'transmitted' via intermediary nodes to the 'end' of the network. Our approach is therefore a 'directed' network; nearly all other analyses use undirected connections. One of the few papers that deploy a directed approach is Brams et al (2006), but these authors are concerned with the way 'influence' is transmitted rather than other kinds of resources.

We should note that our use of the term 'network resources' differs from other potential uses – for example, Gulati (2007) uses it in respect of corporations as those advantages that "…accrue to a firm from its ties with key external constituents including – but not limited to – partners, suppliers and customers, and thus exist outside of a firm's boundaries" (p.3). This is of course an important perspective, but beyond the scope of the current discussion.

Development of the model

To illustrate the development of the approach, it is useful to consider the network of nodes shown in Figure 1[a]. Here each node represents an individual, and the significant interconnections between them are represented as the arcs, and these are reflected in the adjacency matrix M (Figure 1[b]). In this directed network, the arcs represent the potential flow of resources towards the apex of the network ("the bomber") at node 1. Additionally, each node (apart from node 1) is associated with some resources A,B,C etc, and these associations are represented in Figure 1[c].



[a]

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	1	0	0	0	0	0
3	1	0	0	0	0	1
4	0	1	1	0	0	0
5	0	0	0	1	0	0
6	0	0	0	0	1	0

[b]

	1	2	3	4	5	6
A	0	0	0	1	1	0
B	0	1	0	0	1	0
C	0	0	0	0	1	0
D	0	0	1	0	0	0
E	0	0	0	0	0	1
F	0	0	0	0	0	1

[c]

Figure 1: Example Network

The idea of path lengths in a network has been extensively explored and a standard result is that the total number of paths N in a network A_{ij} of length r between and two vertices i and j is given by Equation 1 (Newman 2010:137).

$$N_{ij}^{(r)} = \left[A^r\right]_{ij} \qquad (1)$$

By simple extension it can be shown that the number of paths of length r between node j and product k on the network can be calculated as:

$$D_{kj}^{(r)} = \left[P\right]_{ki}\left[M^r\right]_{ij} \qquad (2)$$

In the example shown in Figure 1, for example, the first, second, third and fourth step links between the nodes and each resource are shown in the ‘access-to-resources’ (ATR) matrices PM, PMM, PMMM and PMMMM in Figure 2. For example, in PM, Node 1 has immediate (i.e. single link) access to resources B and D, while Node 4 has immediate (i.e. single link) access to resources A,B and C. In PMMM, Node 1 has 2 third-order (i.e. three -links) access to resources A, B and C, which represent the routes 1-2-4-5 and 1-3-4-5. It should be noted that one limitation of is that the calculation produces curious results if network has two-way relationships between nodes (as the formula accounts for paths backwards and forwards between nodes); in our model, such relationships are excluded because they contradict the basic assumption of flow towards the apex. However, routes which loop around the network (as in the link from node 3 to node 6) are permitted as being meaningful.

	1	2	3	4	5	6
A	0	1	1	1	0	0
B	1	0	0	1	0	0
C	0	0	0	1	0	0
D	1	0	0	0	0	1
E	0	0	0	0	1	0
F	0	0	0	0	1	0

PM

	1	2	3	4	5	6
A	2	1	1	0	0	1
B	0	1	1	0	0	0
C	0	1	1	0	0	0
D	0	0	0	0	1	0
E	0	0	0	1	0	0
F	0	0	0	1	0	0

PMM

	1	2	3	4	5	6
A	2	0	0	0	1	1
B	2	0	0	0	0	1
C	2	0	0	0	0	1
D	0	0	0	1	0	0
E	0	1	1	0	0	0
F	0	1	1	0	0	0

PMMM

	1	2	3	4	5	6
A	0	0	0	1	1	0
B	0	0	0	0	1	0
C	0	0	0	0	1	0
D	0	1	1	0	0	0
E	2	0	0	0	0	1
F	2	0	0	0	0	1

PMMMM

Figure 2: ATR Matrices

The calculation of these matrices enable the generation of a Summary Matrix (Figure 3) which uses a weighted sum of the access matrices, counting short path lengths as being of greater significance than longer path lengths. Here we use the arbitrary weights $w_1 = 1$, $w_2 = 0.5$, $w_3 = 0.25$ and $w_4 =0.1$. The use of weights in this way in some ways represents an inverted parallel to the use of weights in Borgatti and Li's (2009) discussion of alpha centrality (see also Bonacich and Lloyd 2001): here we assume that in general it is better (from the point of view of the network) for resources to be closer to the 'bomber' than farther away.

SUMMING ACCESS MATRICES WITH (ARBITRARY) WEIGHTS

PM + PMM + PMMM + PMMMM

x1 x0.5 x0.25 x0.1

	1	2	3	4	5	6	SUM
A	1.5	1.5	1.5	1.1	0.35	0.75	6.7
B	1.5	0.5	0.5	1	0.1	0.25	3.85
C	0.5	0.5	0.5	1	0.1	0.25	2.85
D	1	0.1	0.1	0.25	0.5	1	2.95
E	0.2	0.25	0.25	0.5	1	0.1	2.3
F	0.2	0.25	0.25	0.5	1	0.1	2.3
SUM	4.9	3.1	3.1	4.35	3.05	2.45	20.95

Figure 3: Summary ATR Matrix

For more complex networks it would be appropriate to consider a path length greater than 4, but here it is convenient to limit the process for the purpose of illustration. The entries in this Summary Matrix represent an aggregated measure of each node's ease of access to resources, and from these numbers we can extract three measures of particular interest (Figure 4). As Node 1 at the apex of the network is of particular interest, we can use the sum of the column as an indication of the extent to which it can access the resources across the network. Although the absolute number is not of itself meaningful, we can use changes to the network to enable an analysis of the impact of different interventions in the network: we will label this metric the *Customer-Sum-Access-to-Resources* (CS-ATR). Alternatively, we can look at the minimum number in this first column, which – if the resources A-F to constitute, for example, the necessary ingredients for a bomb – gives a measure of the ability of the network to fulfil its intended function: this is labelled *Customer-Minimum-Access-to-Resources* (CM-ATR). Finally, the overall sum of the entries in the Summary Matrix gives an aggregate measure of the extent to which all the nodes have access to the resources. This is of interest in that it provides a proxy for the extent to which the network can operate flexibly and adaptively. This is labelled *Network-Access-To-Resources* (N-ATR). This measure partially reflects the idea of 'network health' developed by Basole and Bellamy (2012), in that it is reasonable to presume that, in general, networks in which many actors have close connection to many resources will be '*productive, agile and resilient*'.

The final stage of the approach now considers how potential network interventions might disrupt or enhance the operation of the network. However, instead of considering the elimination of nodes (for the reasons discussed above), the manipulations evaluated here are:

- Removing or adding a resource from a node
- Removing or adding a link from the network

For each case, the consequence of these changes can be easily assessed for each of the three metrics, and the results expressed relative to baseline of 100 (Figures 5 and 6). Note that in Figure 5 certain links cannot be added because this would introduce direct two-way flow between nodes. These actions can then be translated into ranked lists of potential actions for each metric, and these are shown in Figure 7.

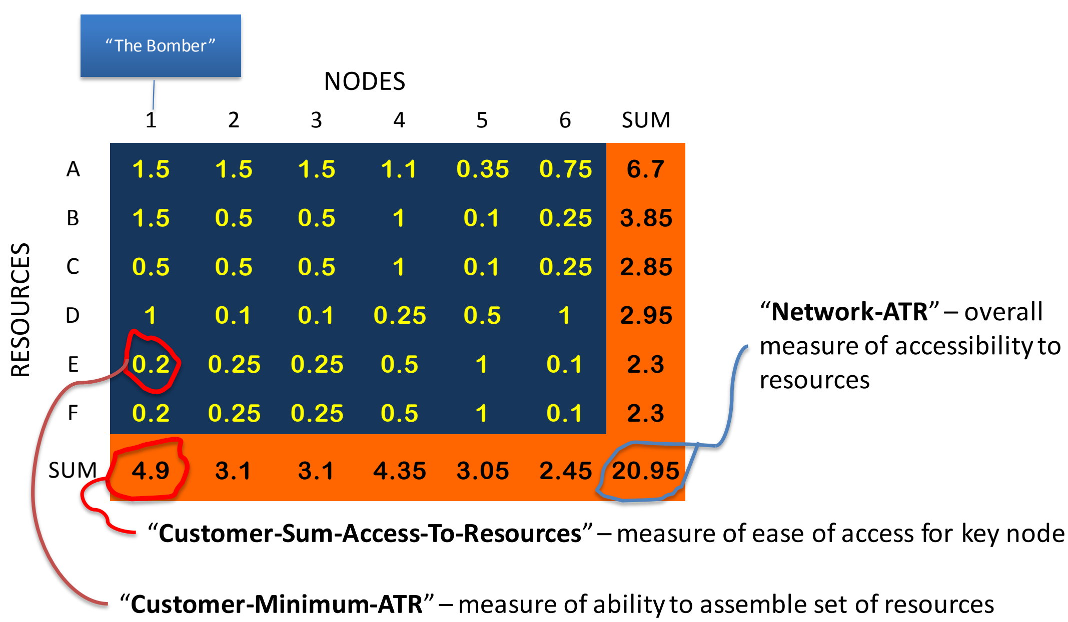


Figure 4: ATR metrics

Customer Sum-ATR

	1	2	3	4	5	6
A	0	120	120	79.6	89.8	104
B	0	79.6	120	120	89.8	104
C	0	120	120	120	89.8	104
D	0	120	79.6	120	110	104
E	0	120	120	120	110	95.9
F	0	120	120	120	110	95.9

Customer Min-ATR

	1	2	3	4	5	6
A	0	100	100	100	100	100
B	0	100	100	100	100	100
C	0	100	100	100	**0**	100
D	0	100	**0**	100	100	100
E	0	100	100	100	100	**0**
F	0	100	100	100	100	**0**

Network ATR

	1	2	3	4	5	6
A	0	105	114	82	86	111
B	0	95	114	118	86	111
C	0	105	114	118	86	111
D	0	105	86	118	114	111
E	0	105	114	118	114	89
F	0	105	114	118	114	89

Figure 5: Effects of adding or removing resources

Customer Sum-ATR

	1	2	3	4	5	6
1						
2	50		121		104	100
3	50	121			104	100
4	163	70	70			100
5	189	143	143	61		
6	162	128		124	92	

Customer Min-ATR

	1	2	3	4	5	6
1						
2	50		100		100	100
3	50	100			100	100
4	225	50	50			100
5	350	225	225	**0**		
6	300	250		350	**0**	

Network-ATR

	1	2	3	4	5	6
1						
2	88		124		122	119
3	88	117			122	81
4	115	78	68			126
5	121	131	148	44		
6	115	121		138	70	

Figure 6: Effects of adding or removing links

Network Disruption

Network ATR

ACTION	OUTCOME (as % of base case)
BREAK 5 to 4	44
BREAK 4 to 3	68
BREAK 5 to 6	70
BREAK 4 to 2	78
BREAK 3 to 6	81
REMOVE A from 4	82
REMOVE A from 5	86
REMOVE B from 5	86
REMOVE C from 5	86
BREAK 3 to 1	88
BREAK 2 to 1	88
REMOVE E from 6	89
REMOVE F from 6	89

Customer Sum-ATR

ACTION	OUTCOME (as % of base case)
BREAK 2 to 1	50
BREAK 3 to 1	50
BREAK 5 to 4	61
BREAK 4 to 2	70
BREAK 4 to 3	70
REMOVE B from 2	80
REMOVE A from 4	80
REMOVE D from 3	80
REMOVE A from 5	90
REMOVE B from 5	90
REMOVE C from 5	90
BREAK 6 to 5	92
REMOVE E from 6	96
REMOVE F from 6	96

Customer Min-ATR

ACTION	OUTCOME (as % of base case)
REMOVE C from 5	0
REMOVE D from 3	0
REMOVE C from 5	0
REMOVE E from 6	0
REMOVE F from 6	0
BREAK 5 to 4	0
BREAK 6 to 5	0
BREAK 2 to 1	50
BREAK 3 to 1	50
BREAK 4 to 2	50
BREAK 4 to 3	50

Network Enhancement

Customer Min-ATR

ACTION	OUTCOME (as % of base case)
LINK 5 to 1	350
LINK 6 to 4	350
LINK 6 to 1	300
LINK 6 to 2	250
LINK 5 to 2	225
LINK 5 to 3	225
LINK 4 to 1	225

Customer Sum-ATR

ACTION	OUTCOME (as % of base case)
LINK 5 to 1	189
LINK 4 to 1	163
LINK 6 to 1	162
LINK 5 to 2	143
LINK 5 to 3	143
LINK 6 to 2	128
LINK 2 to 3	121
LINK 3 to 2	121

Network ATR

ACTION	OUTCOME (as % of base case)
LINK 5 to 3	148
LINK 6 to 4	148
LINK 5 to 2	131
LINK 4 to 6	126
LINK 2 to 5	122
LINK 3 to 5	122
LINK 5 to 1	121

Figure 7: Ranked lists of interventions

Discussion

Although the approach we present here does not presume to displace other approaches to Dark Network analysis, it does offer a potential complement to existing methods. In particular, it has the advantage of presenting a simple and open analytical mechanism that can be implemented without specialist software. In this way it may be easily integrated with other methods. It also emphasises the significance of resources within the network, which may be especially important in certain types of dark networks (for example in relation to IEDs). Rather than telling the user who to 'kill', it provides rankings of potential actions against different metrics. In this way, we suspect it may be an approach that is more amenable to use alongside other types of evaluation and analysis. It is also simple, thereby losing some of the veneer of sophistication offered by some other methods.

These aspects are important because of the potential dysfunctional qualities of more technical analytical tools. In a reflective and thoughtful argument, Erlacher (2013) posits a disconnection between the sophisticated, holistic analysis espoused by US military in some aspects of its work, with its limited ability to enact responses which reflect this sophistication. He writes (concerning the US Military document JP3-60):

> "Its bias toward kinetic targeting undoes its progressive thinking in analysis by linearizing the intervention approach: that is, it would have the U.S. military attack a target as if the target were a unitary actor, rather than a system of systems with vulnerabilities distributed throughout the environment as the manual states." (14)

It is possible that conventional dark network analysis – with its emphasis on identifying nodes for removal – may provide a kind of cultural and conceptual framing which makes a bias to certain kinds of action inevitable. This general issue has been explored in other settings as a kind of technological determinism in analysis (Law et al 2011). This problem may be a particular problem for network theory, in which, according to Berry (2008: 365), *"...we forget that we are using models and think that the world conforms to our network model, or perhaps even worse, when we attempt to remake the world in terms of our network theories*".

Chattoe and Hamill echo this thought (2005:874) in the context of criminal networks:

> "…using formal models that disregard both distinctive ethnographic knowledge of terrorist 'culture' and the working practices and insights of law enforcement agencies. For this reason, it is unlikely to have any lasting policy impact."

In terms of engagement with the results of the analysis, it may be that another advantage of the method may be that it lends itself to tabular presentation (as in the diagrams here); there is some evidence that tables of numbers may be more valuable in practical decision support than traditionally presented node-and-arc diagrams (Beradi 2005; McBride and Caldara 2013). In particular, the approach leads to the consideration of potential (but as yet not existing) links between nodes – which is potentially challenging in a conventional graphical network plot (see Conway 2012).

It is acknowledged that the method described here is presented as a possible approach, and its efficacy and superiority in practice has yet to be confirmed: Sageman (2008:27) warns that academics working in this field are good at generating hypotheses, but not at testing them. Horne and Horgan (2012) emphasise the need for triangulation in research in this field.

Our final observation is that while seeking to provide a framework for supply network analysis applicable to dark networks, it is possible that this approach may have some application for more conventional supply networks, which although different in many ways, share the following features:

- Data is difficult to obtain;
- Networks are not static;
- Understanding the network requires more than the Adjacency Matrix;
- "Access to Resources" is a key concept; and,
- Meaningful resilience analysis needs more than node elimination.

Next steps in the development of this approach include the handle bundles of resources, allowing substitutability between resources, and the handling of simultaneous interventions.

REFERENCES

ACC (2011). *Organized Crime in Australia: 2011 Report*. Canberra: Australian Crime Commission.

Baker, W.E. and Faulkner, R.R. (1993). "The social organization of conspiracy: Illegal networks in the heavy electrical equipment industry." *American Sociological Review* 58/6: 837-860.

Baker, R.M., Raab, J., Milward, H.B. (2012). "A preliminary theory of dark network resilience." *Journal of Policy Analysis and Management*, 31/1: 33-62.

Basole, R.C. and Bellamy, M.A. (2012). "Global supply network health: analysis and visualisation." *Information Knowledge Systems Management*, 11: 59-76.

Battini, D., Persona, A. and Allesina, S. (2007). "Towards a use of network analysis: quantifying the complexity of Supply Chain Networks." *International Journal of Electronic Customer Relationship Management*, 1/1:75-90.

Bellamy, M.A. and Basole, R.C. (2013). "Network analysis of supply chain systems: A systematic review and future research." *Systems Engineering*, 16/2: 235-249.

Beradi, C.W. (2005). *Investigating the Efficacy of Terrorist Network Visualisations*. MSc Thesis, Massachusetts Institute of Technology.

Berry, D.M. (2008). "The poverty of networks." *Theory, Culture and Society*, 25/7–8: 364–372.

Boal, M. (2011). *Zero Dark Thirty* (Screenplay). Los Angeles: Sony Pictures.

Bonacich, P. and Lloyd, P. (2001). "Eigenvector-like measures of centrality for asymmetric relations." *Social Networks*, 23: 191–201.

Borgatti, S.P. (2006). "Identifying sets of key players in a social network." *Computational and Mathematical Organization Theory*, 12: 21-34.

Borgatti, S. P. and Li, X. (2009). "On social network analysis in a supply chain context." *Journal of Supply Chain Management*, 45 (2), 5–21.

Bouchard, M. and Amirault, J. (2013). "Advances in research on illicit networks." *Global Crime*, 14/2-3: 119-122.

Brams, S.J., Mutlu, H. and Ramirez, S.L. (2006). "Influence in terrorist networks: from undirected to directed graphs." *Studies in Conflict and Terrorism*, 29: 703–718.

Bright, D.A. and Delaney, J.J. (2013). "Evolution of a drug trafficking network: mapping changes in network structure and function across time." Global Crime, 14/2-3: 238-260.

Brintrup, A., Kito, T., New,S.J. and Reed-Tsochas, F. (2011). From transaction cost economics to food webs: A multi-disciplinary discussion on the length of supply chains. Paper presented at *Euroma 2011*, Cambridge, 3rd-6th July 2011.

Brzezinski, M. (2002). "Re-engineering the drug business." *New York Times Magazine*, 23rd June, 24–29, 46, 54–55.

Burke, J. (2013). "The new domestic front." *The Guardian*, G2, 23rd April, 6-9.

Erlacher, , M.D. (2013). *Fighting Dark Networks: Using Social Network Analysis to Implement the Special Operations Targeting Process for Direct and Indirect Approaches*. Master's Thesis. Monterey, CA: Naval Postgraduate School.

Everton, S.F. (2012). *Disrupting Dark Networks*. Cambridge: Cambridge University Press.

Everton, S.F. and Cunningham, D. (2013). “Detecting significant changes in dark networks.” *Behavioral Sciences of Terrorism and Political Aggression*, 5/2: 94-114.

Carley, K.M. (2006). “Destabilization of covert networks.” *Computational and Mathematical Organization Theory*, 12:51-66.

Chattoe, E. and Hamill, H. (2005). “It’s not *who* you know, it’s what you know about people you *don’t* know that counts: Extending the analysis of crime groups as social networks.” *British Journal of Criminology*, 45:860-876.

Choi, T. Y., Dooley, K. J., and Rungtusanatham, M. (2001). “Supply networks and complex adaptive systems: control versus emergence.” *Journal of Operations Management*, 19/3: 351–366.

Choi, T.Y. and Hong, Y. (2002). “Unveiling the structure of supply networks: case studies in Honda, Acura and Daimler Chrysler.” *Journal of Operations Management*, 20:469–493.

Choi, T.Y. and Wu, Z. (2009). “Taking the leap from dyads to triads: Buyer-supplier relationships in supply networks,” *Journal of Purchasing and Supply Management*, 15:263-266.

Cobain, I. (2013). “Trapped in the matrix.” *The Guardian, G2*, 15th August, 6-8.

Conway, S. (2012). “A cautionary note on data inputs and visual outputs in social network analysis.” *British Journal of Management*, http://dx.doi.org/10.1111/j.1467-8551.2012.00835.x

Gulati, R. (2007). *Managing Network Resources: Alliances, Affiliations, and Other Relational Assets*. Oxford: Oxford University Press.

Harris-Hogan, S. (2012). “Australian neo-Jihadist terrorism: mapping the network and cell analysis using wiretap evidence.” *Studies in Conflict and Terrorism*, 35/4:298-314.

Horne, C. and Horgan, J. (2012) “Methodological triangulation in the analysis of terrorist networks”, *Studies in Conflict and Terrorism*, 35/2, 182-192.

Hoyer, B. and De Jaegher, K. (2010). “Strategic network disruption and defense.” Discussion Paper Series No. 10-13. Utrecht: Tjalling C. Koopmans Research Institute.

Hurrion, R.D. (1986). “Visual interactive modelling.” *European Journal of Operational Research*, 23: 281-287.

Kin, Y., Choi, T.,Yan,T. and Dooley, K. (2011). “Structural investigations of supply networks: a social network analysis approach.” *Journal of Operations Management*, 29: 194-211.

Kito, T., Brintrup, A., New,S.J. and Reed-Tsochas, F. (2011). Modelling supply networks: a structural analysis of the Toyota supply chain. Paper presented at *Euroma 2011*, Cambridge, 3rd-6th July 2011.

Krebs, V.E. (2002). “Mapping networks of terrorist cells.” *Connections*, 24/3: 43-52.

Law, J. Ruppert, E., and Savage, M. (2011). “The double social life of methods.” Working Paper 95, Milton Keynes: Centre for Research on Socio-Cultural Change (CRESC), The Open University.

Le Carré, J. (2010). *Our Kind of Traitor*. London: Viking

Maurer, D.W. (1955). *Whiz Mob: A Correlation of the Technical Argot of Pickpockets with Their Behaviour Patterns*. Gainsville, FL: American Dialect Society.

McBride, M. and Hewitt, D. (2012). “The enemy you can’t see: an investigation of the disruption of dark networks.” *Working Paper No. 121307*, University of California-Irvine, Department of Economics .

McBride,M. and Caldara, M. (2013). “The efficacy of tables versus graphs in disrupting dark networks: An experimental study.” *Social Networks*, Available online 4 June 2013, http://dx.doi.org/10.1016/j.socnet.2013.04.008

McIllwain, J.S. (1999). “Organized crime: A social network approach.” *Crime, Law and Social Change*, 32: 301–323.

Michalak, T.P., Szczepański, P.L., Narayanam, R., Rahwan, T., Jennings, N.R., Skibski, O. and Wooldridge (2013). “Computational analysis of connectivity games with applications to the investigation of terrorist networks.” *Proceedings of the 23rd International Joint Conference on AI (IJCAI)*, Beijing, August 3-9. University of Southampton ePrints 351020.

Milla, M.N., Faturochman and Ancok, D. (2013). “The impact of leader–follower interactions on the radicalization of terrorists: A case study of the Bali bombers.” *Asian Journal of Social Psychology*, 16: 92–100.

Miklaucic, M. and Brewer, J. (eds.) (2013). *Convergence: Illicit Networks and National Security in the Age of Globalization*. Washington DC: National Defence University Press.

Mizgier, K.J., Jüttner, M.P., and Wagner, S.M. (2013). “Bottleneck identification in supply chain networks.” *International Journal of Production Research*, 51/5: 1477-1490.

Morganthaler, J. and Giles-Summers, B. (2011). *Targeting: Social Network Analysis in Counter IED Operations*. Master’s Thesis. Monterey, CA: Naval Postgraduate School

Morselli, C., Giguère, C. and Petit, K. (2007). “The efficiency/security trade-off in criminal networks.” *Social Networks*, 29:143-153.

Nassimbeni G. (2004). “Supply chains: a network perspective.” In: New, S.J. and Westbrook, R. (eds), *Understanding Supply Chains: Concepts, Critiques and Futures*. Oxford: Oxford University Press. 43-68.

Newman, M.E.J. (2010). *Networks: An Introduction*. Oxford: Oxford University Press.

Ovelgönne, M., Kang, C., Sawant, A. and Subrahmanian, V.S. (2012). “Covertness centrality in networks.” *2012 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining*.

Perliger, A. and Pedahzur, A (2011). “Social network analysis in the study of terrorism and political violence.” *PS: Political Science and Politics*, 44/1: 45-50.

Qi, X., Duval. R.D., Christensen, K., Fuller, E., Apahiu, A., Wu,Q., Wu, Y., Tang, W. and Zhang, C. (2013). “Terrorist networks, network energy and node removal: a new measure of centrality based on Laplacian energy.” *Social Networking*, 2:19-31.

Raab, J. and Milward, H.B. (2003). “Dark networks as problems.” *Journal of Public Administration Research and Theory*, 13/4: 413-439.

Roberts, N. and Everton, S. (2011). “Strategies for combating dark networks.” *Journal of Social Structure*, 12/2.

Sageman, M. (2004). *Understanding Terror Networks*. Philadelphia, PA: University of Pennsylvania Press.

Sageman, M. (2008). *Leaderless Jihad: Terror Networks in the Twenty-first Century*. Philadelphia, PA: University of Pennsylvania Press.

Shen, Y., Ngyuen, N.P., Xuan, Y. and Thai, M.T. (2013). "On the discovery of critical links and nodes for assessing network vulnerability." IEEE/ACM Transactions on Networking, 21/3: 963-973.

Simon, H.A. (1990). "Prediction and prescription in system modeling." *Operations Research*, 38/1: 7-14.

Sparrow, M.K. (1991). "The application of network analysis to criminal intelligence: an assessment of the prospects." *Social Networks*, 13: 251-274.

Spergel, I. (1964). *Racketville, Slumtown, Haulburg: An Exploratory Study of Delinquent Subcultures.* Chicago: University of Chicago Press.

Weinberger, S. (2011). "Social science: web of war." *Nature*, 471, 566-568.

Xu, J. and Chen, H. (2008). "The topology of dark networks." *Communications of the ACM*, 51/10: 58-65.

Implementing Supply Chain visibility to promote fisheries sustainability

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Abstract

Operationalising good practices and better management of marine resources were pursued, in a retailer exploratory case, by following a triple bottom line approach to fine tuning corporate responsibility. Recommendations towards sustainable operations were made, as regards: developing voluntary self-certification towards eco-labelling based on third party; using IT, as a transparency promoter and so, as a leverage for traceability, collaboration and trust across the chain of custody; designing customised policies to deal with different consumer profiles and so, assuring their loyalty by adjusting consumer campaigns; educating consumers as seafood demand regulators. Improvements in Greenpeace evaluation were documented, profit increase was expected.

Keywords: Sustainability in seafood, Supply Chain Traceability, Social Responsibility

1 Introduction

This study presents an empirical research on how the implementation of good practice in fish stocks protection might also contribute to corporate sustainability performance (CSP). The followed view addresses the pursuing of these practices in a retailer, as well as in the upstream stakeholders in the supply chain. In fact, Non-governmental Organizations (NGO) have been calling for the maintenance of both an acceptable and sustainable level of fish stocks (FAO, 2010). Moreover, Governmental Agencies (GA) and Universities have also investigated excessive fishery as a major threat (Till and Markus, 2012). As a consequence, this situation demands for innovative practice towards an environmentally-friendly policy (Laxe, 2010) in the business operations of the sponsor of the current research, a large hypermarket chain. In this way, the following research questions arise (*vide* Figure 1). These questions concern the role of the retailer within the defined scope.

RQi – Can the retailer influence sourcing and trading sustainable practices along the supply chain?

RQii – How to make the consumer purchasing behaviour more sensitive to seafood sustainability?

RQiii – How to organise socially acceptable fish retailing, in order to improve the sponsors image at the consumers, NGO and GA?

Figure 1. Research questions

Nevertheless, these operations should also target the creation of competitive advantage and profitable results. To sum up, the objectives of the research are, as follows: (i) to understand and explain the purpose of corporate sustainable practices; (ii) to address the topic positioned within an integrated context by considering its economic, environmental, and social dimensions; and, (iii) to offer corporate decision makers reliable guidance towards more sustainable business operations in fish retailing.

A case study strategy is pursued in the retailer, in order to achieve the research objectives. However, establishing the research context is so important that a descriptive survey based on a short questionnaire is also applied to the consumers. This mostly quantitative questionnaire aims at collecting the perceptions of a few representative consumers as regards a few economic, environmental, and social dimensions of the context. The surveyed consumers were purposefully chosen among the customers of the store where the exploratory case study took place. This sample is constrained by the duration and the location of the study that were set by the hypermarket sponsor.

While the questionnaire sets a rich context for the situation, the case study enables an in depth understanding of the requirements for sustainable fish retailing. Therefore, socially acceptable operations suggest the design of a working tool that might enable the traceability of the supplier's activity concerning the several fish species. By using a database implemented in a spreadsheet, reports providing guidance to manager's action can be generated as a significant outcome. These reports treat, organise, consolidate and summarize data collected by observation, interviews and internal document analyses. External data sources, such as Greenpeace reports, e.g. ship owner's blacklists, are also used. A traffic-light system (TLS) (Caddy, 2002) is implemented to classify the fish capture features, based on the spreadsheet database. The TLS was also used to provide very clear information to the consumer about how critical is the sustainability status of each fish species. In this situation, the taxonomy is based on the Greenpeace red list which informs about the species at risk.

It should also be added that the reported questionnaire is supported on a thorough literature review in order to improve its construct validity. Moreover, it is validated by a pilot study. On the other hand, the reliability of the case study is improved by keeping the gathered documentation in a file, as well as by creating a case protocol (Yin, 1994: 33, 64, 95). At last, only analytic generalization might be possible due to the chosen design for the research, which mainly addresses the specific situation of the sponsor.

The developed *Database* helps the retailer to control the business procedures of its replenishment sources. In fact, fisherman and fish owners are under both economic and social pressure to accomplish the fishery policies of Governmental Agencies, i.e. avoiding overfishing, illegal fishing and unsustainable fishing methods. The sponsor and its supply chain are currently pursuing business practices also closely focused on the environmental and social dimensions, in addition to a stricter orientation towards profit. Another contribution for the practitioner is the operationalisation of real world procedures in order to be pursued a corporate performance that is more sustainable because it is strategically aligned with the other stakeholders, i.e. both final customers (consumers) and suppliers. Thus, the proposed Database System is expected to contribute to increase the loyalty of the customers by implementing a fishery policy that values the sustainability of both ecosystems and sea species, in line with the principles defended by the Blue Ocean Institute (BOI, 2013). On the other hand, the *Traffic Light* is a core system that visually reports and highlights the conclusion of the knowledge accumulated and treated in the database. The Traffic Light System (TLS) is included both in the Database and in the labels of the fish that is being sold. Another use of the TLS promotes a very easy way to make the customers aware of the impact of their purchasing options in the species at risk and, hopefully, much more responsible.

A few limitations arise from the study, as follows:

- TLS implementations that mainly address fish captured in the sea;
- just using a Greenpeace red list;
- self-certification process;
- consumer lacking information;
- weak involvement of all stakeholders and modest use information technology provide insufficient supply chain transparency and limited trust;
- no real time, on-time information across supply chain;
- sample of purposefully chosen customers;
- constrained robustness of the pilot-test;
- no partnership with scientific institutions;
- no literal and theoretical replication (Yin, 1994: 45-7).

Limited fish traceability was successfully introduced by the provision of critical information to the consumers. There is a huge need to develop a CPFR approach and the consumers did exhibit an unacceptable behaviour pattern. This research proposes the continuing of the briefing and sensibilisation of the consumers by both eco-labelling and marking fishes accordingly to the Traffic-Light System, following the Greenpeace orientations. The pursued approach is aligned with what most of the competition does, Its usefulness is based on establishing good sourcing, working and trading practices for a chain of hypermarkets and also on diagnosing the status of the art for businesses that might be classified as "followers". It is argued for an innovative contribution as concerns setting three types of consumer profiles, which might enable the fine tuning of future consumer campaigns and so, improving customer loyalty and business turnover.

Next sections of this paper are, as follows. In section 2, a literature review is carried out. In section 3, the results of the exploratory case study are presented and analysed. Then, discussion and final conclusions will close the report over the research questions and the objectives.

2 Literature review

2.1 Status of the art of sustainable fishing

The mismanagement of oceans resources brings serious consequences for life on Earth. Oceans are approaching the threshold of environmental recovery. Therefore, this is the right time to change the mindset and to implement its sustainable management.

An increase in scientific research concerning topics, such as acidification (Fenchel, 2011), ocean warming (Lyman et al., 2010), habitat loss (Airoldi et al., 2007), and the appearance of so called “dead-zones” has driven the shifting of attitudes (Schrope, 2006). So, indifference as regards the marine environment is no longer an option, particularly when we consider the effects of the overexploitation of fisheries (Shakouri et al., 2010).

Indeed, a growing global population over 7 billion, has led to an ever-rising demand for seafood and also to a resulting increase in fishing effort. The latest FAO figures report that 32% of marine fisheries are overexploited, depleted or recovering from depletion, having increased from 10% in 1970 (*vide* figure 1). A further 53% of fisheries are being exploited at their maximum level and, many of them, without the management measures in place to prevent over-exploitation (FAO, 2010).

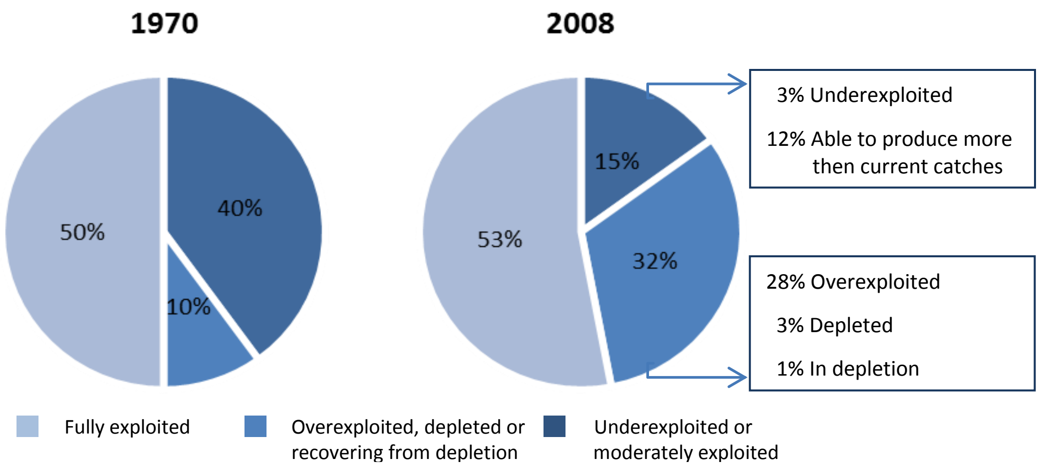

Figure 2. The increase in fisheries exploitation since 1970. Source: FAO (2010: 8)

Still according to FAO data, the remaining 32 plus 15 percent of fisheries is not enough to overcome the excess fishing pressure and it yields less than their maximum potential production. In summary, the increasing trend in the percentage of overexploited, depleted and recovering stocks and the decreasing trend in underexploited and moderately exploited stocks provide a serious cause of concern.

2.2 Economic, social and ecological management of fisheries

Fisheries represent the last major international industry based on the chasing and gathering of wild animals. It is neither primitive nor innocuous, and fishing remains as an essential element of food supplies that is vital for the well-being of hundreds of millions of people (Pauly et al., 2003).

Nowadays, the higher demand levels of fishing are a major threat to the structural and functional (re)organization of marine ecosystems: direct effects regard the reduction of both the temporal and spatial distribution of the target species, habitat damage and a sharp drop in the average size of captured fishes (Andersen et al., 2008). Indirect ones concern causing or enhancing changes in the fish community structure or differential effects on shoal functional groups (Greenstreet et al., 1999). Efforts are currently being made to understand the wider effects of fishing, to measure them (Pauly et al., 2003) and to set quotes concerning fish stocks (FAO, 2010; Shakouri et al., 2010), because the increasing evidence of the collapse of many species.

The collection of such data is often quite expensive and it requires a continuous research effort with an adequate monitoring system and, expertise that is not always available. The outcomes of this research must be robust enough to support the management of fisheries on a sustainable basis and to promote higher sustainable levels of both fish stocks and catches. Fisheries are core subjects for the balance of fish stocks in marine ecosystems, and healthy ecosystems are a key element to the continuity of the fisheries business, like an economic-ecological virtuous circle.

Fisheries also involve more socio-economic objectives, coming from fishing revenue since they provide employment for millions of people, worldwide, from fisherman to aquaculture producers and, from traders and intermediaries to wholesalers. This sector might play a fundamental role in preventing and reducing poverty, in developing countries (FAO, 2010). However, sustainably managed fish stocks have to rely on just 19% of the total fish stocks (*vide* Figure 2) to ensure the long term feasibility of all these livelihoods. In this way, the remaining stock is being recovered.

The progress made by Government Agencies (GA), Universities, Research Centres and Non-governmental organizations (NGO) is getting results in reducing exploitation rates and, restoring both overused fish stocks and marine ecosystems (Till and Markus, 2012). The adoption of the Code of Conduct for Responsible Fisheries (1995) illustrates this issue.

Control measures for illegal fishing on the high ocean, where no state has authority, do exhibit serious drawbacks as regards the law enforcement (EJF, 2012). According to Greenpeace (2013), the most problematic areas are located around West Africa where the “pirates” illegally catch tonnes of fish, destroying the economies of nearby countries. Each year, illegal fishing in the waters of sub-Saharan Africa is estimated in 1.2 billion Euros. Often, culprits are Chinese, Korean and Taiwanese vessels that have licenses to fish in one zone but, then, exploit another one (Wall Street Journal, 2007). Most illegal catches are exported to Europe through the Spanish port of Las Palmas. Fish illegally caught are transhipped at sea onto large refrigerated cargo vessels, where they are mixed with legal catches before being transported to their final destination port (EJF, 2012).

With regard to combating Illegal, Unreported and Unregulated (IUU) fishing, reinforced controls have been developed, such as: (i) the elaboration of an international legally-binding instrument (COM, 2008) on port measures to prevent and eliminate IUU fishing; this is mainly due to international cooperation, monitoring and control measures applied to the whole chain of fishing and related activities; (ii) a governmental partnership framework that develops a sustainable fisheries policy and responsible exploitation of fishery resources (FAO, 2010); and, (iii) the search for harmful fishing methods (*e.g.* like the bottom-trawl), parallel trading and lack of compliance with standards relating to minimum size of captured species (Jacquet & Pauly, 2007).

On the other hand, NGO Greenpeace, to prevent illegal fishery outcome from entering the supply chain, developed and recommends the following two initiatives: (i) the traceability of fishery products; and, (ii) the use of Greenpeace Blacklists, *i.e.* lists of boats that are not authorized to fish or that have already been punished for illegal fishing activities. All Blacklists concerning fishing vessels and fish transport vessels, including their owners or operators and companies, where compiled from the Official International Blacklists. This information is based on the official registries of IUU fishing that are publicly available and accessible in Greenpeace (2013) webpage.

Developing frameworks for achieving responsible sustainability is imperative to operationalise knowledge and to enforce good practice across the supply chain, from fishermen to retailers (FAO, 2010). These frameworks should enable a transition to sustainable fisheries management in the form of support for fisheries improvement projects, demand for certified origin of seafood and its traceability up the supply chain. Private sector should also be fully committed to these actions in order to contribute to a quick recovery of shoals from extremely low population levels.

2.3 Retailers and Supply Chain Sustainability

In the fish supply chain the captured fish is sent to market through processors, distributors and retailers before ending up on consumers hands (Figure 3). The effort of the producer (fishing fleet) is depicted as providing feedback to the ecosystem model by impacting fish abundance and catches of both target and non-target species (*vide* also Thrane et al., 2009). Aquaculture units can also be incorporated as producers or processors as best suited in individual applications (Christensen et al., 2011). In this way, the liability to ensure the chain sustainability by an environmentally-friendly policy (Laxe, 2010) belongs to all the participating parties, in the business operations across all the supply chain (*vide* RQi).

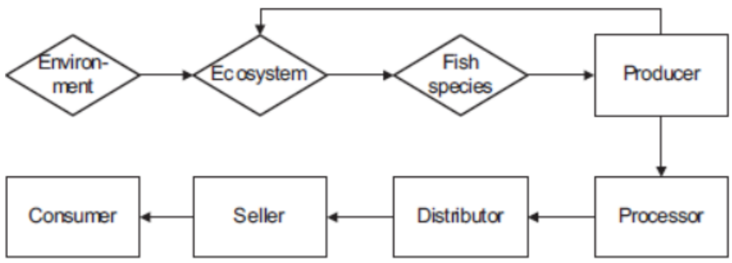

Figure 3. Schematic value chain flows from sea to consumer for a single fish species. Source: Christensen et al. (2011)

Environmental pressures constitute driving forces to improve the sustainability of supply chains (Linnenluecke and Griffiths, 2010; Zhu et al., 2011). Many times, environmental damages are not acknowledged once that (i) they do not impact market price formation in early stages of unbalance; (ii) they occur too far away from the marketplace; and, (iii) product is not yet scarce. Thus, a clear link between supply chain strength and firm environmental performance becomes explicit (Vachon and Mao, 2008) and supply chains must become integrated by considering both upstream and downstream stakeholders (RQi). Connolly and Caffrey (2011) suggest the existence of additional tiers both upstream and downstream not shown in Figure 3 (e.g. Figure 4). In fact, business processes and management components of the supply chain are closely inter-related with the depicted structure (Lambert et al., 1998).

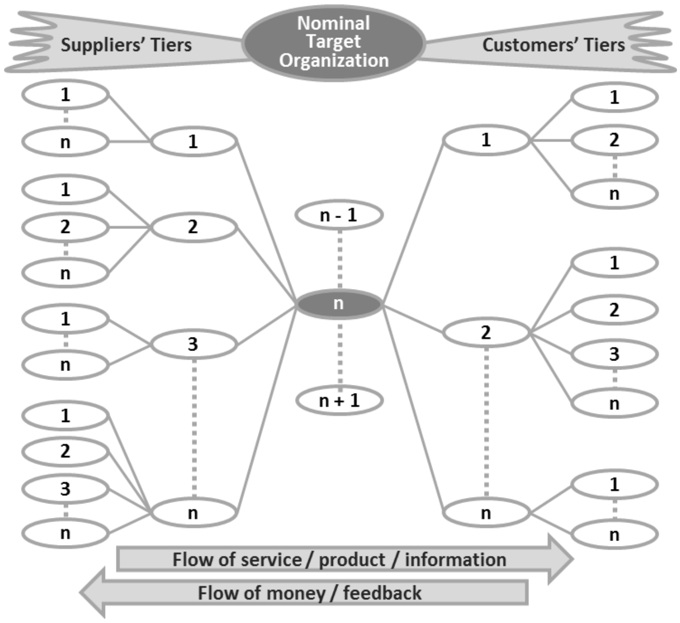

Figure 4. Schematic of a generalized supply network. Source: Connolly and Caffrey (2011)

In this context, due to their strategic position and market influence, retailers play a core role in driving supply chain environmental sustainability (David-Styles et al., 2012; Minten et al., 2009). Indeed, retailers are drivers to Fair Trade, offering substantial contributions for achieving sustainable development (COM, 2002), by the provision of information, user-friendly tools and spread of sustainable practices (RQii). Retailers usually avoid risk since they are very sensitive to social or environmental problems of consumers. Moreover, according to Greenpeace (2008) the high and unpredictable price of damaging the marine biodiversity has led to a growing social awareness that has been demanding the sustainability of the fish species being consumed. Thus, retailing has progressed towards stopping to offer threatened fish species, refusing illegal fishing, criticizing destructive capture methods and offering more friendly alternatives (RQi). However, the results of the Greenpeace survey on fish procuring policies adopted by major retailers, in Portugal, drew strong criticism to all the addressed Portuguese hypermarkets. In fact, still in 2008, strategies concerning fish procurement were not made available to the public, or they even were missing, despite their importance in the retail landscape (Greenpeace, 2008). Finally, according to Caniato et al. (2012) supply chain management (SCM) might also help companies to pursue environmental responsibility. However, few studies have analysed the relevance of SCM in contributing to environmental sustainability (RQi).

2.4 Robust Management of Fisheries: monitoring, informing and enforcing

Clear standards are helpful to set milestones, agree on end-objectives and promote responsibilities definition for partners upstream the supply chain. Retailers could apply several strategies to drive environmental improvement in the fish supply chains, such as: fish traceability; product certification; environmental criteria for suppliers; dissemination of better practices across suppliers; promoting captured fish eco-labelling; local sourcing; and, optimization of logistics (Caniato et al., 2012). Secondly, the market-based approaches of retailers might push and empower customer choice in sustainable consumption. In turn, this change in the consumer attitude might influence and be transferred upstream the supply chain to the remaining stakeholders, increasing the incentive to entail strategies in the demand for sustainable seafood (Vazquez-Rowe et al., 2012) (RQiii).

2.5 Product certification, eco-labelling and Traffic Light System (TLS)

Eco-labels are seals of approval given to products that are less harmful to the environment than some similar competitors (*vide* also OECD 1991 p.12). The principal objective of eco-labelling is to create a market-based incentive for sustainable management of fisheries by creating consumer demand for seafood products from well-managed stocks. It is possible to distinguish between two subcategories of multiple attribute labels; one that mainly focuses on the fishing stage, (arrows 1–3, in Figure 5) and another one that addresses the 'environmental' impacts in the whole life cycle of the products (*vide* arrows 1–5, in Figure 5) (Thrane et al., 2009; Christensen et al., 2011).

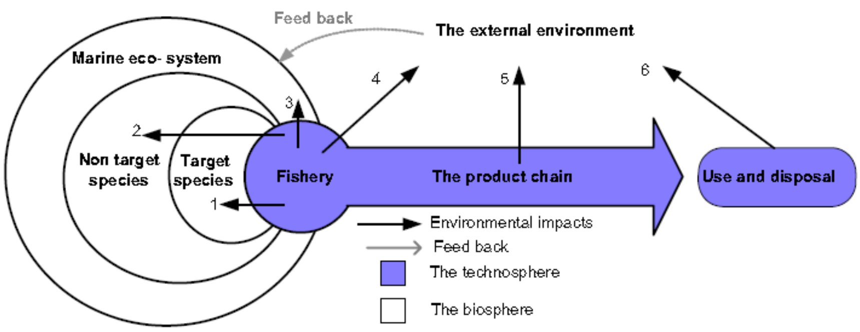

Figure 5. Environmental impacts at different life cycle stages of seafood products. Source: Thrane et al. (2009)

Type II environmental labels of the International Organization for Standardization (ISO) are based on "self-declared" or "self-certified" environmental claims by producers, importers and retailers on products and services on a voluntary basis (*vide* also IISD, 2013; EEC, 2013), based on their own product standards. The standards might be based on sustainability criteria related to specific environmental issues against which a fishery is to be evaluated.

Product certification and eco-labelling have important differences as currently applied in fisheries, while interrelated and serving the same goal. Product certification is commonly a measure mandated by governments, often mutually agreed upon by regional fisheries management organizations, in order to ensure that only legally harvested and reported fish landings can be traded and sold in the domestic or international markets. Product certification does not necessarily involve a product label at the retail level (Wessells et al., 2001).

The TLS (Caddy, 2002) was found as a useful visual tool, to operationalise effective monitoring and reporting, in a rapid and cheap manner. It supports the decision making process by: (i) describing the pressures affecting the ecosystem; (ii) allowing timely risk analyses and global assessments concerning fisheries management; (iii) updating retailers on fisheries capture and trade issues in a sustainable manner; (iv) tracking progress towards meeting management objectives; and, (v) by clearly communicating both trends in complex outcomes and management processes, to a non-specialist final consumer audience.

In summary, there is a growing awareness that retailers have a vital role to play in promoting more sustainable patterns of consumption. and, in Portugal, 70% of the fish is sold in hypermarkets (Greenpeace 2008). Moreover, the vast majority of consumers visit food retail outlets on an almost daily basis (Mintel, 2008, 2010) (RQi). So, food retailers should design schemes to provide consumers with more and better information to make decisions when purchasing seafood (RQii). On the other hand, retailers are the active intermediaries between primary producers, manufacturers and consumers and so, they can be seen in a singularly and powerful position that drive sustainable consumption (RQiii).

3 Case study in a large retailer

The research sponsor is a leading retailer company that owns super and hypermarkets spread all over Portugal. The company believes that taking measures to preserve the environment is a distinctive competence that might contribute to the business sustainable development and so, to Social Responsibility. Therefore, it has been developing a fish procurement policy to recover from initial competitive disadvantage by defining both responsible and sustainable trading business practices targeting to stop selling the species in risk (Greenpeace, 2008b).

Therefore, the sponsor policies have been driven by a long-term approach to risk management, in which, as many uncertainties and threats as possible might be controlled. For instance, the sponsor is taking the first steps in this direction by reducing in 10% fish caught by trawling and committing itself to eliminating illegal fishing by stop doing business with the Greenpeace blacklisted firms. Conformance with these criteria was checked every year. This strategy is expected to contribute to both business sustainability and value creation.

The described pilot-test was carried out in the fishery department of a store chosen by the sponsor as representative, regarding size, area, localization, population and product assortment. Investigated products concerned fresh (sea waters and aquaculture), frozen and dried (cod) fish.

3.1 Data collection

Data were collected from several critical sources, as follows: (i) documents, databases and the sponsor website were searched for motivations, advantages and goals of the sponsor fishery policy, in order to find out the previous sustainability strategies of the company; (ii) the ranking of the sponsor and other retailers was searched from the Greenpeace website to benchmark the sustainability levels and healthy competition; (iii) 'Docapesca de Matosinhos' and 'Docapesca de Peniche' were two of the visited suppliers to trace the sources of the supplied fish; (iv) suppliers blacklists were downloaded from the Greenpeace website; these were cross-checked with the sponsors suppliers to eliminate the blacklisted ones; (v) the Whole Foods Market was visited, in London, in order to understand and assess its decision making system; two portals[1] were also consulted; (vi) 153 purposefully chosen customers of the sponsor were surveyed; the applied questionnaire was about seafood purchasing behaviour, ability to identify the species in extinction risk and environmental protection policies: reactions and perceptions; the results coming from the PASW Statistics Software were sufficient to define a very first exploratory consumer profile, which enabled the sponsor to focus its policies.

3.2 Results analysis

3.2.1 Survey – the consumer perceptions about seafood sustainability

153 sponsor customers selected by convenience sampling were inquired by following a structured interview. The store, study duration and working shift were chosen by the sponsor. So, results generalization was compromised. In this exploratory survey despite

[1] http://www.wholefoodsmarket.com/ and http://www.blueocean.org/

data being quantitative, the analysis was qualitative, because statistical significance was not addressed. Therefore, the average values registered in the graphics might only be interpreted in a qualitative way.

Understanding the consumer perception was an important driver of a future consumer campaign that was questioned in three ways, as follows: (i) relevance of capture method and risk species as purchasing criteria; (ii) general consumer behaviour towards sustainability practice, i.e. prices variations or species offer; and (iii) consumer behaviour when purchasing popular species.

a) Purchasing criteria

The average importance allocated to each purchasing criteria by respondents in a scale ranging from 1 (not important) to 4 (very important) was depicted in Figure 6.

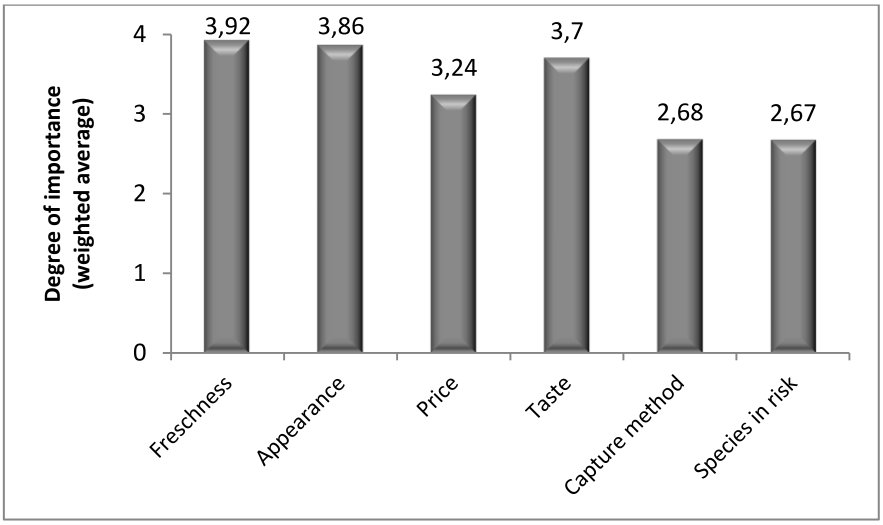

Figure 6. Average importance allocated to each purchasing criteria.

Sustainability criteria – capture method and risk species – showed a relevant qualitative smaller degree of importance perception when compared with others. However, respondents still showed high sensitivity, i.e. two thirds of the scale (≈ 2,7 out of 4), which might mean that any potential consumer campaigns towards sustainability would have some kind of impact.

b) Sustainability practice and general respondents behaviour

The average agreement allocated to each business practice by respondents in a scale ranging from 1 (totally disagree) to 4 (totally agree) was depicted in Figure 7.

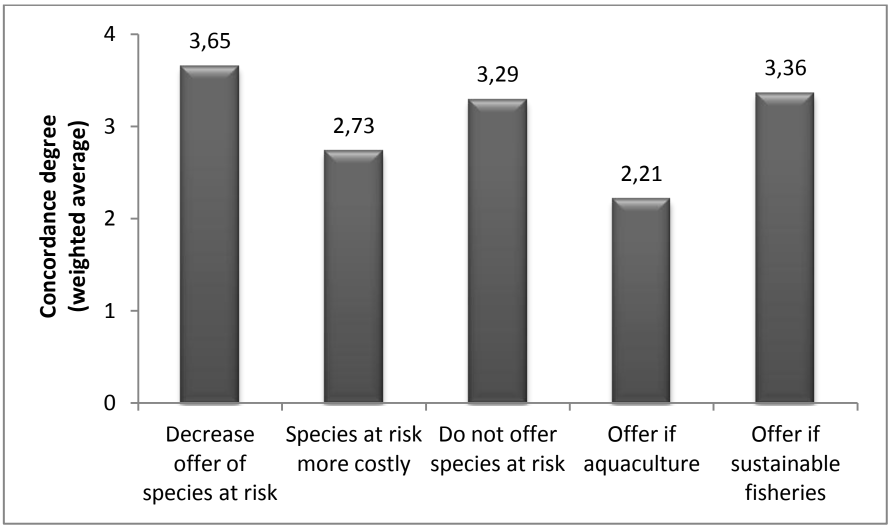

Figure 7. Average agreement allocated to each sustainability practice,

One might notice qualitative differences among the average scores allocated to two groups of practices. Furthermore, many respondents agreed that risk species should not be sold or, at least, its offer should decrease. However, as many respondents still thought that if the specie was being captured by sustainable fisheries, it should be made available, even if it was at risk. Perhaps, some information to the consumer was being required since the qualitative differences among the average scores were noticeable. A significant number of respondents argued for risk species becoming more costly. Only half of the respondents agreed that risk species should come from aquaculture, which showed a relevant improvement opportunity.

c) Specific respondents behaviour when purchasing popular species

Risk species part of traditional national diet were chosen from a list built by Greenpeace (2008b) (red, in the species TLS) and the ones regularly purchased were identified (yes/no). Species risk status was only perceived by 19% of the respondents. Supplying some information could have motivated respondents to change their consuming patterns, e.g. holding the desire, abstaining to consume, replacing the risk species, choosing aquaculture.

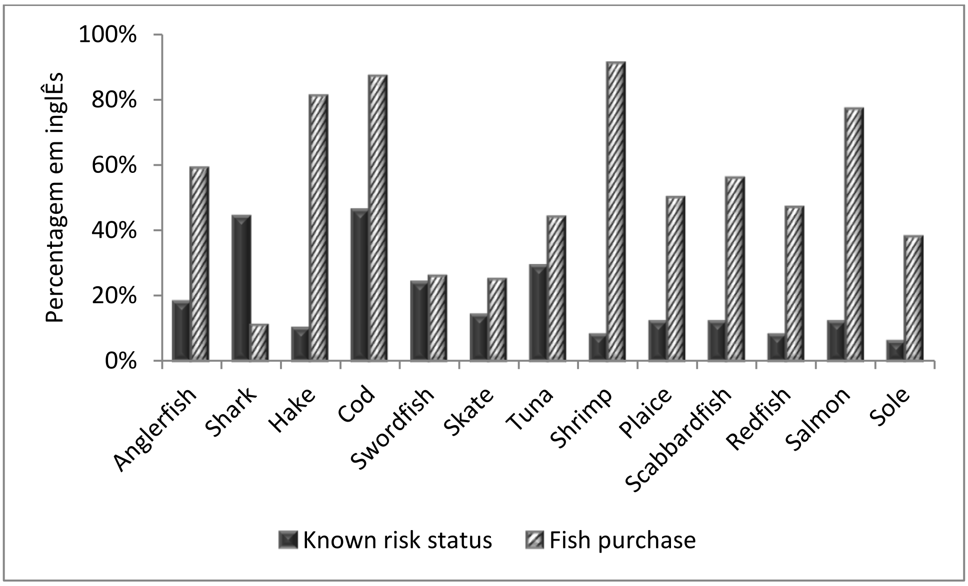

Figure 8. Respondent's knowledge about seafood species at risk being offered and purchased

Different motivations for high consumption rates were identified since cod fish was considered a national dish, hake was very popular fish because it could be cooked in several ways, it was cheap, healthy and recommended by the nutritionists, shrimp has become popular lately because the income level rose sharply and salmon was consumed due to a price drop (aquaculture). There were two misunderstandings, as follows: the species at risk was the oceanic salmon and fresh tuna consumption was only high as a canned product. To sum up, some difficulties might be anticipated as regards the change of the consumption patterns of cod, hake, shrimp and tuna in Portugal.

d) Overall analysis of the survey results

Consumers[2] appeared to have been buying a relevant amount of seafood without being aware of the risk status of the species. Figure 9 describes three expected behaviour types, if consumers were more aware of the sustainability issues concerning the species (RQii).

Defining a retailer policy according to these three consumer profiles might result into better matching the consumer purchasing behaviour. Thus, it would be important to design a more robust survey as regards construct validity. Then, the above identified consumer profiles could be refined through an in depth socio-demographic characterisation. This should be followed by a thorough definition of the adequate variables to assure seafood sustainability, as previously exemplified in the exploratory survey. Moreover, internal validity should also be taken into consideration by setting stronger relationships among the variables.

[2] It is recognised that this "generalization" from respondent to consumer needs to be checked. From now on "consumer" will be used to avoid semantics complexity, since that there are expressions like "consumer campaigns" that should not be replaced.

(i) Not sensitive – Definition: consumer not sensitive to the species risk, after having been informed

Description: if the species availability is reduced, goes out of the product assortment, or price increases, this customer is expected to run away to the competition

(ii) Fully devoted – Definition: consumer fully devoted to the species protection, after having been informed

Description: if sustainability is pursued this customer might exhibit a proactive behaviour; it is expected to stop consuming or to replace a risk specie either by a non-risk, **or** by aquaculture

(iii) Me too – Definition: consumer that is more and more aware of the species risk, but only after a continuous information effort

Description: if species are captured by sustainable fisheries, this customer might accept to purchase it and it might be retained by actions targeting the loyalty improvement

Figure 9. Definition of consumer profiles

In this way, both better discrimination between the several measured categories and statistical relevance might enhance the explanatory power. Therefore, the chosen retailer policies concerning sustainable seafood consumer campaigns would be focused on the consumer profiles through a credible investigation. These campaigns might also align the producer with a sustainable integrated policy to the whole supply chain, which would be driven by the marketplace.

3.2.2 Design of a database to implement a traceability policy

Consumer profiles (ii) and (iii) mentioned the requirement for sustainable fishery, i.e. capture methods adequateness and/or blacklists ship-owner compliance. Thus, species threats would decrease, risk species stocks would tend to recover and the others would be more protected.

In this way, data that were collected, treated and recorded in a database enabled higher control and an easier access to the organised information concerning the traceability of both fish capturing and some processing activities, according to Greenpeace recommendations (Greenpeace International, 2008). The developed database was made up of the attributes considered in the fields of the model expressed in Table 1.

Table 1. Database model to implement a traceability policy adopted by the sponsor

TLS of the Capture Method	Supplier	Product	Scientific Name	Capture Zone	Fishing Method	Boat List	Owner	Statement on the issue of quotas	Port List
...	...	...	...	...	...	...	...	...	...
	"X_1"	SNAPPER	*Pagrus pagrus*	Atlantic North	Long lining	CRISTIANO	"Y_1"	Catch Certificate	Rio de Janeiro
	"X2"	HORSE MACKEREL	*Trachurus trachurus*	Atlantic North	Purse seines	CARLOS APARÍCIO	"Y_2"	Catch Certificate	Peniche
	"X_2"	HAKE	*Merluccius paradoxus*	Atlantic North	Trawl	GALATADA	"Y_3"	Catch Certificate	Canárias
...	...	...	...	...	...	...	...	...	...

Note: Suppliers, boat and company names have been disguised for confidentiality reasons.

The colour codes used in the table came from treating and categorizing the several species according to the method of fishing and further implementing a TLS methodology to accept or reject a supplier. While the red concerned trawling capture, the green included manual fishing, long lining, hooks on branch lines (snoods), Danish seines, fishing with creels and buckets. Finally, the yellow classification regarded other capture methods rather than the mentioned ones and also, multi-method of fishing put together in the same boat.

While a few suppliers have argued for confidentiality, others reported difficulties due to their positioning in the supply chain as excuses to deny the required information. Perhaps some enforcement through a contractual clause as a qualifying criterion would help to overcome these difficulties towards the green supply chain led by the retailer.

3.2.3 Product certification and eco-labelling for fisheries sustainability

The self-declaration/self-certification of the safety, quality and sustainability of supplied fish assured the origin from sustainable fisheries in the label, by correctly describing the species without re-labelling, by stating the capture date and the species risk, by assuring traceability within the chain of custody and so, that there was no transhipment at sea of illegally caught fish. Despite, the eco-label only focused on the fishing stage, i.e. in the target species (*vide* arrow 1, Figure 5), consumers at the POS[3] were directed to purchase products that had fewer ecological impacts. Thus, eco-labels operationalised a market based approach that attempted to influence consumer behaviour towards more sustainable seafood. On the other hand, the principal objective of product certification and catch documentation was accomplished, i.e. to prevent, discourage and eliminate IUU fishing (FAO, 2001) since that only legally harvested and reported fish landings could be traded.

In summary, the retailer influenced both sourcing by product self-certification and trading by eco-labelling. It might be argued that sustainable practices along the supply chain have been implemented by this assignment (RQi).

[3] POS – Point of Sales

3.2.4 Business impact – Greenpeace ranking

Our sponsor has progressed from the fourth position (2008), in the Greenpeace Supermarket Ranking, to the second one, in 2010 (Figure 10). The reported research was carried out during 2010 and so, it did also play a relevant role in the definition of a more sustainable policy for fish procurement and trading in the sponsor, as regards excluding IUU fishing, seafood traceability and eco-labelling, preservation of risk species, SC visibility improvement.

The position occupied by the sponsor hypermarkets had resulted from the accomplishment of criteria, established by Greenpeace, after the Code of Conduct for Responsible Fisheries (FAO, 1995) targeting the recover of the global stock level of seafood until 2015.

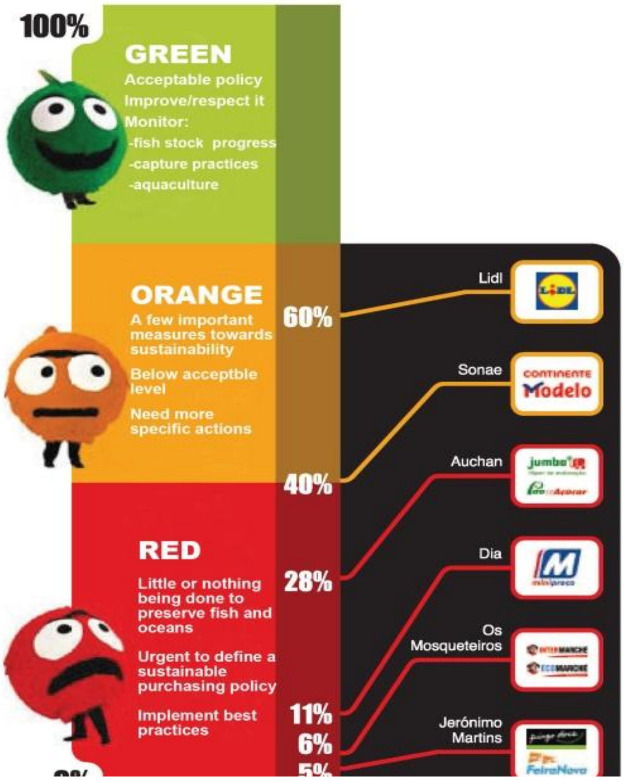

Figure 10. Results of the Third Supermarket Ranking (Greenpeace, 2010)

These results suggested that the retailer had been pursuing a socially acceptable fish retailing policy. It was both clear and confirmed that its image had improved near the consumers and also by NGOs, like the Greenpeace (RQiii).

3.3 Results discussion

3.3.1 Sponsor's positioning at the Greenpeace ranking for Portuguese retailers

Many institutions are working together to develop strategies targeting the consumption patterns change through the marketplace, in addition to government regulation to improve fishery production (Iles, 2007). The sponsor improved its positioning at the Greenpeace qualitative ranking for the Portuguese retailers (Figure 10) by voluntary coping with its guidance. In fact, supermarkets can be the driving force to push local fisheries towards sustainability at a faster rate than is currently being pursued by government (UNEP, 2009).

3.3.2 Product certification and eco-labelling for fisheries sustainability

The used "Red List of Greenpeace" for finding out the species at risk might be questioned, in the same way that just lists of recommendations, websites and reports are used to differentiate between sustainable and unsustainable species (Iles, 2007). Moreover, Christensen et al. (2011) suggest that fishing quotas should be as dynamic, as shoals behaviour, be periodically revaluated and include both non-target species and the ecosystem, as a whole. The eco-labelling carried out in this research, only focused on the target species (arrow 1, Figure 5) of the "Red List" leaving an improvement margin.

Christensen et al. (2011) illustrate the required holistic approach by considering the effect of an eventual overfishing of a particular predator in a food web (e.g. Tuna), on the population of their preys (e.g. Mackerel), and even, the effect of the consequent population increase of this prey, as a predator itself, over other species (e.g. Mackerel, on Clam population). They also draw up the economic impact of the ecosystem balance on job creation (Figure 11). So, stopping overfishing and allowing the stocks to rebuild would increase their productivity and it would maximize revenues to the industry and commerce in the long run (Shao, 2009). Thus, the sponsor path could be improved by keeping track of the flow from production to trade within a broader context (social, economic and ecological).

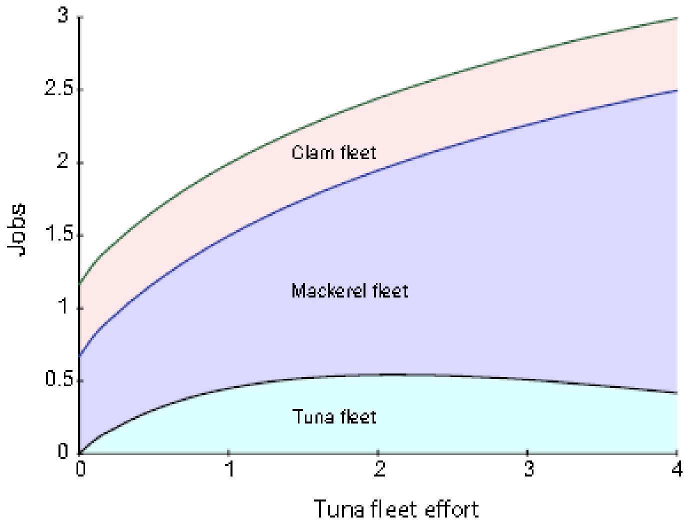

Figure 11. Number of jobs as a function of the effort of the tuna fleet. Source: Christensen et al. (2011)

The natural progress of "self-declared"/"self-certified" environmental labelling by producers was towards "environmental labels [...] based on voluntary multi-criteria product life-cycle assessment of environmental effects with verification through a third party"[4] (Wessells et al., 2001). Thus, the sponsor must soon need to choose a third party certifier. According to Jacquet and Pauly (2010) the Marine Stewardship Council (MSC) has become the world's most established fisheries certifier and is taken more seriously by scientists than many other organisations. However, they consider that objections to MSC certifications have been growing (*vide* also Martin et al., 2012). Therefore, some scientists, the Greenpeace, the Pew Environment Group, and some national branches of the World Wide Fund (WWF) have protested over various MSC procedures or certifications. MSC certification has also been questioned by retailers like Waitrose (in 2009) and Whole Foods (in 2010) by refusing to deal with certified fisheries (Jacquet et al., 2010).

[4] Type I environmental labels of ISO

3.3.3 Supply chain, visibility, traceability & IT as promoters of trust and sustainable views

Marine resources can be better managed when fishers and other resource stakeholders are more involved in management and co-management (Phillipson, 2002). Focusing on only species can hide the identity of, and variability among, producers and fisheries (Iles, 2007). Iles also argues that many internal policies and activities are not transparent to outsiders. Finally, the MSC advocates a "boat to plate" approach to certification which implies a requirement for traceability (Jacquet and Pauly, 2010).

It looks unquestionable the call for the involvement of all stakeholders in a shared holistic view focused on the customer (Figure 12). Moreover, providing visibility leveraged by information technology was found as significant steps towards trust and so, to build up a credible approach to sustainability. It was not enough just to accept the word of the suppliers about their sustainable practices, as an act of pure faith. The sponsor should make sure that there was evidence and visibility of the upstream activities supported by periodic random audits, by credible third parties and, also, by adequate realtime IS/IT solutions, since that paperwork was becoming increasingly questionable.

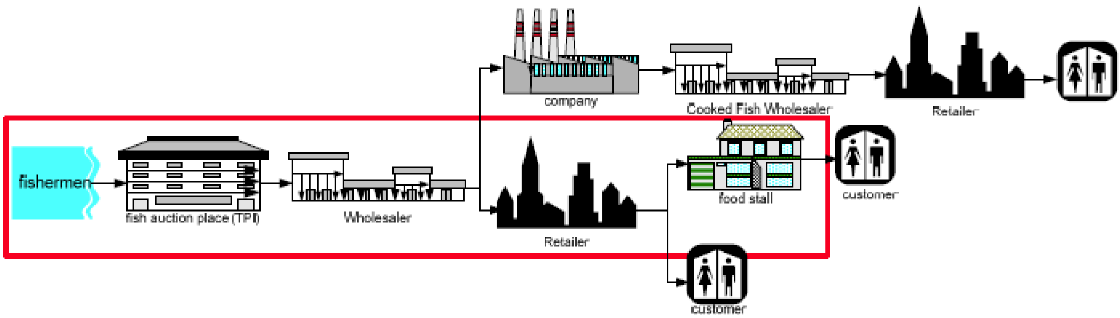

Figure 12 Red square: sample of sea fishery for consumption supply chain. Source: Widyaningrum and Masruroh (2012)

In fact, nowadays, it is possible to track vessels in the ocean (e.g. Vessel Tracking Globally, EMSA webpage), even in real-time. Thus, if this is not done, reasons might be, as follows: (i) no financial resources; or, (ii) lack of political will, due to high economic interests (?); or, (iii) insufficient social/market pressure.

Despite the research sponsor having a very limited size at the international context an effort should be done to lead its supply chains towards transparency and trust, going further than designing a database to record the self-reported activity of the fisheries (*vide* Table 1). So, information dissemination, labelling and credible means of signalling are rising in importance, in order to provide feedback to customers and other stakeholders about the environmental quality, social and economic benefits of both seafood and the supply chain processes (Karl and Orwat, 1999; de Boer, 2003). Then, consumers should more easily understand the need to consume more fish from aquaculture origin and, to be ready to pay more for dearer wild-caught seafood products (Figure 7) and acting as demand regulators, i.e. accepting self-imposed limits on fish consumption, stopping purchases of certain species, or stopping to buy sustainably caught species (Iles, 2007).

4 Conclusions

This paper addressed the state of the art of fish retailing practices, in order to achieve better management of marine resources. The research succeeded to understand the consumer view and to introduce fish traceability to some extent, since neither CPFR approaches, nor IS/IT solutions are in place.

The research purpose was exploratory and a pilot-store was chosen by the sponsor, as representative. 153 customers were inquired and selected by convenience sampling method. Thus, a broad generalization of the results was not possible. The average values plotted in the graphics were interpreted in a qualitative way. So, statistical significance was not addressed. Further work to overcome some of the study limitations was identified, as follows: to make the pilot-test more robust, as regards, an enlarged duration, choosing the test period in order to include/exclude special seasons or events, cover other stores or improving critical store procedures. However, before that, the existing data could be quantitatively analysed by using tools from multivariate statistics, i.e. factorial analysis and cluster analysis, to make a preliminary confirmation of the main purchasing criteria and, also, of the consumer profiles that were identified.

The exploratory survey disclosed the potential consumer awareness of purchasing criteria close to sustainability. In the future, a rigorous statistical survey should be carried out, to check the absolute level of importance of these criteria for the consumers. Consumer campaigns could be reinforced and multiplied accordingly. If the criteria, which concern sustainability, do not show any relevance, then consumers might need to be educated and to become sensitive to the problem, first of all (RQii).

Moreover, the questionnaire revealed that consumers appeared to be open to some action regarding species at risk, such as reducing offer, increasing price, or practising sustainable fishery. Action should be taken to make aquaculture more popular, as it already happened with species like salmon, sea bream and bass (RQii). Perhaps, this had occurred in the same way with chicken, but, nowadays, practically everybody are happy to eat the abundant, half-priced hens coming from the poultry farming industry. The positive point was that respondents appeared to be prepared to accept a financial penalty, as regards consuming seafood species at risk, exactly the same way consumers pay double-price for free range chicken.

Finally, the survey highlighted the consumer availability to purchase species at risk that were captured by sustainable fishery, which generated what appeared to be a clear demand on information. Consumers appeared to have no information concerning the risk status of many popular species that were offered by the sponsor. Two actions were taken in order to provide more information to the consumer, as follows: (i) a ‘first’ Traffic Light System (TLS), concerning the sustainability of the fisheries, was supported by a purposefully constructed database based on Greenpeace blacklist; (ii) a ‘second’ TLS was built to classify the species at risk based on the red lists of Greenpeace. The fishing quota could have been addressed depending on the periodic dynamics of shoals and it should also have included the non-target species and the ecosystem, in addition to the target species. Despite the database supported by partner’s self-evaluation being a current practice in the industry, strong criticism was arising as regards the transparency of the process in the chain of custody. In fact, the implemented schemas to operationalise the influence of the retailer on sourcing and trading sustainable practices (RQi) were found insufficient. Thus, recommendations were made, as regards the progress towards eco-labelling based on third party certification, in which context the role of the Marine Stewardship Council (MSC) was discussed, as a popular and credible certifier entity. Finally, a supply chain approach leveraged by information technology, as a promoter of visibility and so, of trust, was also discussed as a more sustainable view.

The "boat to plate" MSC approach to certification supported by modern IT systems to track both vessels and activities across the supply chain, in real-time, was proposed. This should provide both transparency and evidence of sustainability practices, aiming at dealing with modern consumer pressure within a CPFR environment. The consumers should also be educated to acting as demand regulators, to consuming aquaculture fish rather than wild-caught seafood, to self-imposing consumption limits, to stop buying risk species and to be prepared to paying more for the wild species. It is argued that retailers did appear to have a core role as regulators of the supply chain, since they could act as perfect mergers of the upstream and downstream interests, by orchestrating both consumer and producer convergent campaigns (RQi). In this way, the retailer role should go far more beyond than just promoting the progress towards balanced marine ecosystems based on an effort to stop selling the species in risk or, merely eliminating the blacklisted fisheries (RQiii).

As regards the economic dimension, one argues that there is a relevant contribution to the practitioner, i.e. the sponsor. In fact, three types of consumer behaviour were anticipated, if the level of consumer awareness increased, as follows: not sensitive, fully devoted and me too. This consumer segmentation needs to be confirmed by designing a more robust survey, where an in depth socio-demographic characterisation would be carried out, as well as, a thorough definition of both the adequate variables to assure seafood sustainability and their relationships. In this way, the retailer might be able to design more customised policies to deal with different consumer needs, in order to assure their loyalty by adjusting the consumer campaigns (RQiii). As a consequence, a positive impact in profitability might be expected, not only directly concerning the purchasing of seafood, but also in other types of products.

At last, it is argued that the objectives of this research were fully achieved, since that the current corporate sustainable practices were understood and explained (i), the topic was addressed after a triple bottom line approach (ii) and there was a relevant contribution to practice, enabling the fine tuning of business practice (iii), during this exercise of promoting sustainability in fisheries by discussing the implementation of visibility in supply chain.

Selected References

Airoldi, L. and Beck, W. (2007). Loss, status and trends for coastal marine habitats of Europe. *Oceanogr. Mar. Biol. Annu. Rev*., 45, pp. 345–405.

Anderson, M.J., Gorley, R.N. and Clarke, K.R. (2008). *PERMANOVA + for PRIMER: Guide to Software and Statistical Methods.* PRIMER-E: Plymouth, UK.

BOI – Blue Ocean Institute (2013). Retrieved March, 16, 2013, from: http://blueocean.org/

Caddy, J.F. (2002). Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. *Fish. Res*., 56, pp. 133–137.

Caniato, F., Caridi, M., Crippa, L., Moretto, A. (2012). Environmental sustainability in fashion supply chains: an exploratory case based research. *Int. Journal of Production Economics*, 135, pp. 659-670.

Christensen, V., Steenbeek, J. and Failler, P. (2011). A combined ecosystem and value chain modelling approach for evaluating societal cost and benefit of fishing. *Ecological Modelling*, 222, pp 857-864.

Code of Conduct for Responsible Fisheries (1995). Article 12.18.

COM (2002). Corporate Social Responsibility: A business contribution to Sustainable Development. retrieved March, 16, 2013, from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri= COM:2002:0347:FIN:EN:PDF

COM (2008). Commission of the EU communities. (Brussels, 28.5.2008). retrieved March, 16, 2013, from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008: 0333:FIN:EN:PDF

Connoly, P.L. and Caffrey, L. (2011). Supply Chaining fishery advice. *ICES – Journal of Marine Science*, 68(8), pp. 1706-1711.

De Boer, J. (2003). Sustainability labelling schemes: the logic of their claims and their functions for stakeholders. *Business Strategy and the Environment*, 12 (4), pp. 254–264.

Environmental Justice Foundation (EJF) (2012). "Pirate Fishing Exposed: The Fight Against Illegal Fishing in West Africa and the EU" (retrieved March, 16, 2013, from: www.ejfoundation.org

Environment Ecolabel Catalogue (EEC) (2013). retrieved March, 16, 2013, from: http://ec.europa.eu/ecat/

FAO (1995). Code of conduct for responsible fisheries Rome, Italy, 41pp. retrieved March, 16, 2013, from: http://www.fao.org/docrep/005/v9878e/v9878e00.HTM

FAO (2001). International plan of action to prevent, deter and eliminate illegal, unreported and unregulated fishing. Rome, Italy, 24pp. Retrieved March, 16, 2013, from: (http://www.fao.org/docrep/003/y1224e/y1224e00.HTM

FAO (2010). *The State of world fisheries and aquaculture*. Rome, Italy.

Fenchel, T. (2011). Ocean Acidification: A National Strategy to Meet Challenges of a Changing Ocean, National Research Council of the National Academies. *Marine Biology Research*, 7(4), pp. 418-419.

Greenpeace (2008a). Uma receita para o desastre: o apetite insaciável dos supermercados por peixe, Greenpeace Internacional, J.N.152, Amsterdam. Retrieved March, 16, 2013, from: http://www.greenpeace.org/portugal/PageFiles/51829/1-ranking-supermercados.pdf

Greenpeace (2008b). Lista vermelha dos peixes, retrieved March, 16, 2013, from: http://www.greenpeace.org/portugal/Global/portugal/report/2008/6/lista-vermelha-peixes.pdf

Greenpeace (2010). Uma receita para a biodiversidade supermercados: ingredientes para preservar a vida dos oceanos, Greenpeace International, J.N.313, Amsterdam. Retrieved March, 16, 2013, from: (http://www.greenpeace.org/portugal/PageFiles/51810/ranking3.pdf.

Greenpeace International (2008). Modelo de Política Sustentável e Responsável de Peixe para Supermercados, retrieved March, 16, 2013, from: http://www.greenpeace.org/portugal/PageFiles/52583/modelo-politica-retalhistas.pdf

Greenpeace (2013). Retrieved March, 16, 2013, from: http://www.greenpeace.org/international/en/campaigns/oceans/pirate-fishing/Blacklist1/

Greenstreet, S., Spence, F, Shanks, A. and McMillan, J. (1999). Fishing effects in NE Atlantic shelf seas: patterns in fishing effort, diversity and community structure II. *Fisheries Research*, 40(1), pp. 107-124.

IISD (2013). The ISO 14020 series. retrieved March, 16, 2013, from: http://www.iisd.org/business/markets/eco_label_iso14020.aspx

Iles, A. (2007). Making the seafood industry more sustainable: creating production chain transparency and accountability. *Journal of Cleaner Production*, 15, pp. 577-589.

Jacquet, J. and Pauly, D. (2007). The rise of seafood awareness campaigns in an era of collapsing fisheries. *Marine Policy*, 31, 308–313.

Jacquet, J. and Pauly, D. (2010). Opinion Seafood stewardship in crisis. *Nature*, 467, pp. 28-9.

Karl, H. and Orwat, C. (1999). Economic aspects of environmental labeling. In: Folmer, H., Tietenberg, T. (Eds.), *The International Yearbook of Environmental and Resource Economics 1999/2000*. Edward Elgar, Cheltenham (UK), pp. 107–170.

Lambert, D., Cooper, M. and Pagh, J. (1998). Supply chain management: Implementation issues and research opportunities. *International Journal of Logistics Management*, 9(2), pp. 1-19.

Laxe, F. (2010). Dysfunctions in common fishing regulations. *Marine Policy*, 34, pp. 182–188.

Lyman, J.M., Good, S.A., Gouretski, V.V., Ishii, M., Johnson, G.C., Palmer, M.D., Smith, D.M. & Willis, J.K. (2010). Robust warming of the global upper ocean. *Nature*, 465, 334–337.

Linnenluecke, M. and Griffiths, A. (2010). Corporate sustainability and organizational culture. *Journal of World Business*, 45, pp. 357–366.

Jacquet, J., Pauly, D. , Ainley, D., Holt, S., Dayton, P. and Jackson, J. (2010). Seafood stewardship in crisis. *Nature*, 462(2), pp. 28-29.

Martin , S.M., Cambridge, T.A. , Grieve, C , Nimmo, F.N. and Agnew, D.J. (2012). An Evaluation of Environmental Changes Within Fisheries Involved in the Marine Stewardship Council Certification Scheme. *Reviews in Fisheries Science*, 20:2, 61-69.

Mintel, (2008). Food retailing – UK – November. Retrieved March, 16, 2013, from: http://academic.mintel.com/sinatra/oxygenacademic/searchresults/show&/display/id=280627

Mintel (2010). Sustainability in the Food Chain (Industrial Report) - Ireland - October 2010. Retrieved March, 16, 2013, from: http://academic.mintel.com/display/483570/?highlight=true#

Minten, B., Randrianarison, L. and Swinnen, J. (2009). Global retail chains and poor farmers: evidence from Madagascar. *World Development*, 37, pp. 1728-1741.

OECD (1991). Environmental Labelling in OECD Countries, OECD, Paris)

Pauly, D., Alder, J., Bennett, E., Christensen, V., Tyedmers, P. and Watson, R. (2003). The future for fisheries. (State of the Planet), *Science*, Vol.302(5649), pp.1359-1362.

Phillipson, J. (2002). Widening the Net. Prospects for Fisheries Co-Management, http://www.ncl.ac.uk/cre/publish/Books/Fishfinal.pdf (Accessed in March, 2013).

Schrope, M. (2006). The dead zones. *New Scientist*, Vol.192(2581), pp.38-42.

Shakouri, B., Yazdi, S. and Fashandi, A. (2010). Overfishing. *2nd International Conference on Chemical, Biological and Environmental Engineering* (ICBEE 2010).

Shao, K. (2009). Marine Biodiversity and Fishery Sustainability. *Journal of Clinical Nutrition*, 18(4), p. 527.

Styles, D., Schoenberger, H. and Galvez-Martos, J. (2012). Environmental improvement of product supply chains: Proposed best practice techniques, quantitative indicators and benchmarks of excellence for retailers. *Journal of Environmental Management*, 110, pp. 135-150.

Thrane, M., Ziegler, F. and Sonesson, U. (2009). Eco-labelling of wild-caught seafood products. *Journal of Cleaner Production*, 17, pp. 416–423.

Till, M. and Markus, S. (2012). The Law and Policy Behind the Upcoming Reform of the Common Fisheries Policy. *Journal for European Environmental & Planning Law*, Vol. 9 (3-4), pp. 257-284.

UNEP – United Nations Environment Programme (2009). The Role of Supply Chains in Addressing the Global Seafood Crisis, DTI/1218/PA, http://www.unep.ch/etb/publications/Fish%20Supply%20Chains/UNEP%20fish%20supply%20chains%20report.pdf (Accessed in March, 2013).

Vachon, S. and Mao, Z. (2008). Linking supply chain strength to sustainable development: a country-level analysis. *Journal of Cleaner Production*, 16, pp. 1552-1560.

Vazquez-Rowe, I., Hospido, A., Moreira, M. and Feijoo, G. (2012). Best practices in life cycle assessment implementation in fisheries. Improving and broadening environmental assessment for seafood production systems *Trends in Food Science & Technology*, 28, pp. 116-131.

Vessel Tracking Globally (LRIT) Europeaan Maritime Safety Agency (2013). Retrieved March, 16, 2013, from: http://emsa.europa.eu/operations/lrit.html.

Wall Street Journal (2007). "Global fishing trade depletes African waters," 23 July 2007, retrieved March, 16, 2013, from: http://www.illegal-fishing.info.

Wessells, C., Cochrane, K., Deere, C., Wallis, P., and Willmann, R., (2001). Product certification and ecolabelling for fisheries sustainability. FAO FISHERIES TECHNICAL PAPER 422.

Widyaningrum, D. and Masruroh, N. (2012). Development of the Sea Fishery Supply Chain Performance Measurement System A Case Study, *Int. J Sup. Chain. Mgt*, vol. 1 (3), pp. 20-32.

Yin, R. (1994). *Case study research: design and methods*. 2nd ed., Sage Publications, Inc., USA.

Zhu, Q., Geng, Y. and Lai, K. (2011). Environmental supply chain cooperation. *Journal of Industrial Ecology*, 15, pp. 405-419.

5Rs Concepts in Manufacturing Fashion Clothing - MFC Applied to Textile Waste

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Abstract

This article is a survey on the use of the concepts of 5Rs as a strategic tool to minimize the environmental impacts generated by the solid waste resulting from the cutting department of Manufacturing Fashion Clothing - MFC. The processes run by that manufacture are intense, involving a network of companies with the goal of producing products of fashion.

Products MFC have specific characteristics provided by the design which gives, by way of creation a style for the avid consumers of products in diverse forms and different in their colors, especially with small-batch production and short life cycle, making it the almost exclusive.

From an environmental standpoint the cutting department within the MFC, has a great responsibility and strategic positioning that can significantly contribute to minimizing the impacts of waste generation.

Keywords: Fashion, Clothing, Manufacturing, 5Rs, Textile Waste

1. Introduction

In the production process of the manufacture of fashion apparel - MFC are several types of solid waste generated at each stage of the production process. The list have an extensive and ranges from pieces of cardboard, plastic and Styrofoam used in packaging and protection of raw materials received to flaps, tissue papers and scrap generated in the steps of cutting and sewing.

This study presents a part of research on the use of the concepts of 5Rs as a tool to minimize the negative effects of solid waste generated by the cutting department of MFC. The processes executed by this manufacturing are intense and involve an extensive network of companies.

The cutting department within the MFC an important property of the environmental standpoint due to the generation of tissue fragments in large quantities in handling. Usually consist of woven yarn waste composition which consists of various types of fibers difficult to identify, for later use, resulting in problems for its proper use and disposal projects.

According to Fletcher (2011), many raw materials and inputs used in confections are associated with some form of environmental impact or lack of concern with sustainability concepts. The effect of using the fiber vary according to the types and scales of the processes.

Are materials that affect the ecological and social systems and cause various impacts: aquatic ecotoxicity, chemical pollution, loss of biodiversity, natural resources depletion, human toxicity, climate change and high production of solid waste.

Given the impact of various environmental problems caused by the forms of the mode of production and consumption, issues related to the environment have attracted the concern of citizens around the world in search of solutions. The concepts started with the principles of the 3Rs. (Reduce, Reuse, Recycle/Repurpose), currently in the public domain, evolved into the current 5Rs. (Reduce, Reuse, Repurpose, Recycle and Rethink).

The concept of the R's started to be used as tools by some fashion companies aiming to minimize the disposal of solid waste generated by the cutting department. Leite (2009) states that at some point the goods are produced from post-consumer. It is necessary, therefore, to enable controlled media to dispose of these goods in the environment.

This study is justified, on the one hand the social importance of the textile sector in the economic context, because it is one of the main generators of employment and income in many countries, especially in Brazil, and secondly, by pollution and waste produced along its chain. It is a field of study in need of research material and with little adequate bibliography designed to proposals related to the concepts of sustainability within the Manufacturing Fashion Clothing - MFC.

1.1. Research Methodology

The objective of this research is to expand theories, describe and explore situations and not to enumerate frequencies. There is a needs to be a closer researcher to sources of research seeking to understand the phenomena from the perspective of the subjects, the participants in the situation under study. The choice of method rests on the need to shed light (insight) on a particular subject, describing behaviors or classify facts and variables.

In the present investigation no sources of theoretical methodology of different authors such as Yin, Godoy and Lakatos, who showed no single theory that presents a set of actions in order to enable the collection of data and information from a company that participates in empirical scenario a little studied and documented.

Due to the characteristics of the segment researched this article adds a case study from a qualitative exploratory study in which questions "how" and "why" were the basis of the investigation. The observations were made on the spot, with semi-structured interviews in order to engender features and links theoretical importance.

2. Economic Importance of the Brazilian Textile Sector

The importance of the textile sector at the global level is remarkable. According to IEMI (2012), while the global textile production grew 34.2% between 2001 and 2010, international trade in textiles and clothing increased 82.7%, reaching a total of U.S. $ 648.6 billion, of which, in year 2011, statistics accuses a record U.S. $ 756.3 billion.

The Brazilian Textile Chain produced in 2011, U.S. $ 67.3 billion, equivalent to 5.6% of the total value of production in the manufacturing industry, not considered the activities of mining and construction (IEMI, 2012).

	Nº companies	Workers (thousand)	Production tons. (thous./year)	Prodution USD (millions)
Spinning	438	75,5	1.301,7	6,7
Weaving	586	100,0	1.342,3	12,5
Knitting	2.639	109,9	553,5	6,5
Textile dyeing	1.266	43,4		
Textile manufactures	27.700	1.316,3	1.899,6	63,3
Totals	32.629	1.645,1		
Garment manufactures	24.365	1.130,1	1.232,3	50,9

Table 1 - Comparative data of the Brazilian textile sector. Source: IEMI (2012)

Table 1 shows, in Brazil, the importance of the clothing segment in relation to the numbers presented in each item analysis - number of companies, employees, production in tons and values in USD.

It is striking the relevance of the garment manufacturing segment represents 74.67% of the total number of companies in the sector and 68.69% of the employment of labor. In terms of value, is natural the outstanding position of garment manufacturing, since it comes to final products that add value of the weaving and knitting industry.

Brazil produces per year, 170,000 tons of waste from the textile industry it's not properly utilized by the industry itself, via reverse logistics or in another sector of the economy. More than 90% of residual tissue are improperly discarded as informs ABIT (2012).

3. Strategy to Focus on Differentiation

Can highlight the relevance of certain authors, for which, under different perspectives, adopt various models strategy has been essential to the achievement of business success in MFC.

According to Slack et al (2002), a business strategy and competitive strategy of an organization is to define its mission and individual goals, focusing on how it intends to compete in their markets. The strategy should be developed by each business area of the company, establishing parameters relationship with its customers, markets, competitors and the organization to which it belongs.

Horte et al (1987) argue that the main function of the production strategy is to conduct business with the production capabilities to facilitate the choice of competitive strategy over time. The concept of manufacturing strategy arises from the need to integrate the operational process of a production unit to the overall decision-making process of the company.

According to Porter (1986), Leadership Differentiation involves the supply of goods or services with certain unique features in the market. The difference may be situated on brand image, in design, technology, or services Custom peculiarities and network of suppliers, for example. Leadership Focus refers to a particular group of consumers, a segment of the product line or a particular geographic market. In both, comprise up various advantages and some disadvantages according described by the author.

One of the most valued strategies currently it is the diversification increasingly frequent market presented by the variety of models and constantly develop new products, a result of the aspirations of the buyer. Among the fields of competition described by Contador (1996) are: a) the Product Project, which values the features, functions, performance and appearance of the product or service, b) Quality Product / Service, which is the result of increasing awareness of the company and the producer in order to meet the requirements and needs of the consuming public.

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4. Textile Chain and the Fashion

4.1. Textile Chain

According to Mendes (2010), the Textile Chain consists of a set of consecutive steps, along which the various inputs undergo some kind of transformation to the formation of a final product and its marketing. It is a succession of operations which involves, besides processes, functionally integrated services adding value to the final product. All businesses suffer greater or lesser influence of the fashion cycle.

Figure 1 shows the industries and services network that participate in the Textile Chain, and the lesser or greater degree of interference of fashion movements their interrelationships and level.

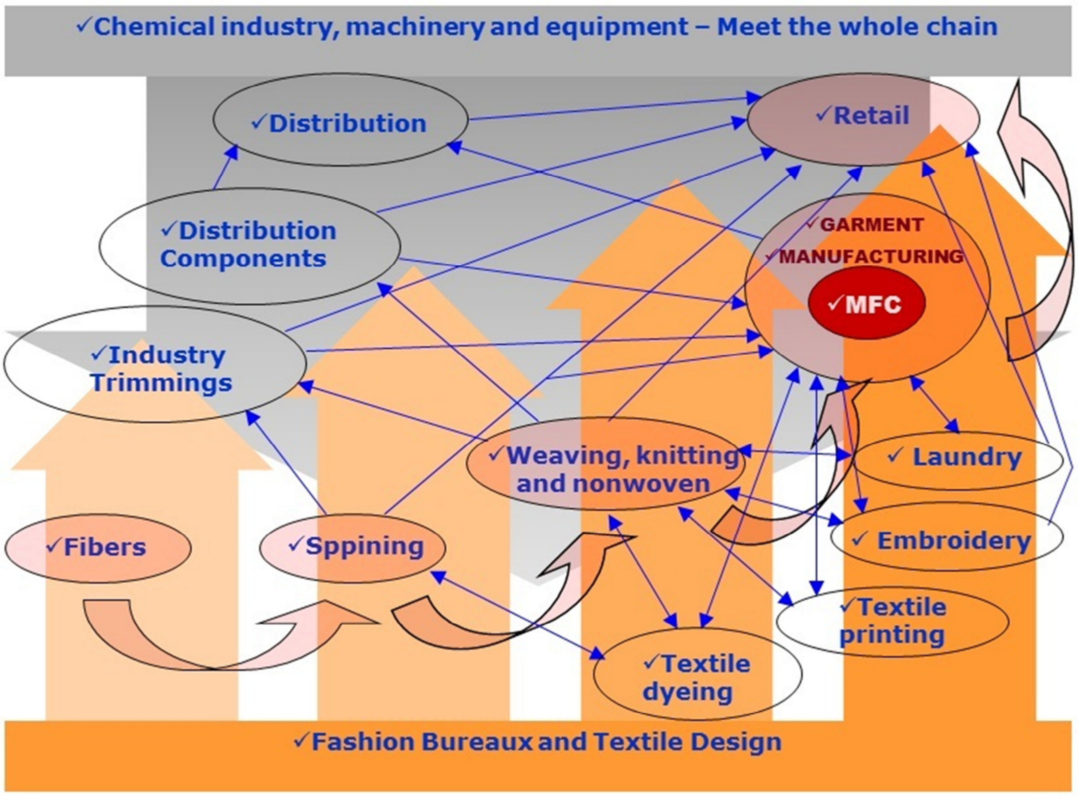

Figure 1 - Network of companies and location of MFC. Source: MENDES (2010)

It is observed in Figure 1 the main axis composed of fiber production, spinning, weaving, knitting and nonwoven, manufacturing and retail.

The fibers group comprises agriculture (animal, plant), manufacturing industry (mixed fibers and mineral) and chemical (synthetic fibers).

The wiring in Brazil, supplies raw material to the group weaving, knitting and non-woven. Supplies also outside the main shaft, industry trims and retail market.

The group weaving, knitting and nonwoven maintains relations with almost all other actors in the chain or through direct delivery, or by two-way (two-headed arrow), as in the case of dyeing, printing, embroidery and laundry. Are treatments processing and applications made in the raw material.

4.2. Fashion

According to Lipovetsky (1989) the fashion system would temporal dynamics itself that produced modernity. It can be argued that fashion has the temporal dynamics of the consumer society, as a facet of its logic is ephemeral, and one of its foundations is obsolescence.

Souza (1987) defines fashion as a term more restricted, reserved for periodic changes in dress styles and other details of personal adornment.

In contemporary societies, fashion is one of the most striking phenomena in the dynamics of consumption. Even the individual who refuses to join any "fashion", is somehow connected to it. Fashion is not only related to the act of dressing, relates to a conglomeration of information that guide behaviors and vary with time. In this context, included topics such as music, architecture, literature, and other universes that change according to the time. (RECH, 2000).

5. Fashion Product

According to Kotler (2000), the product is the first and most important element of the marketing mix of the company and deserves attention for being responsible for the financial results of the organization, regardless of distribution channel.

Renfrew and Renfrew (2010) add that the development of a product requires research and investigation to meet the needs of customers and know the best positioning in a competitive market.

Rech (2002) conceptualizes fashion product as any item or service that combines the properties of creation (design and fashion trends), quality (conceptual and physical), wearability, appearance (presentation) and price from the wills and desires of market segment to which the product is intended.

To Udale and Sorger (2009) the company need to acquire or develop and launch new products more often, to keep the customer's attention toward the brand. Kotler (2000) contributes to ponder what new releases define the company's future, as new aftermarket products should be designed to maintain or increase sales and avoid competition win customers

The fashion garment product for to consumer is very elaborate and is the result of several phases of research that start in the fashion world trends in new materials (yarns, fabrics, trims and processing) available and new shapes and volumes imagined by the creators international. As a result, there is the creation of innovative products in very diverse forms and the high level of differentiation in textures, colors and prints.

In each season the fashion needs to present wide variety and novelty in their shapes, colors, materials and textures, enabling brands producing fashion garments reach different audiences. The goal is to satisfy the desires of the public more bold and innovative, that accompanying fashion and more conservative than consumes a more measured fashion. Nowadays fashion can be considered democratic, since it is the protagonist is the consuming public in making decisions about what should be produced.

The production of the clothing sector is composed of a variety of products types for different customers The consumer market can be segmented by age, gender, income level, and other factors The focus is on meeting the needs and expectations of the consumer, so the design of a product has its beginning and end in the figure of the consumer. (TUTIA, 2008)

6. Manufacturing Fashion Clothing - MFC

The MFC and its service providers are impacted by the fashion cycle constantly suffering strong influence of national movements and / or international fashion trends represented by the Bureaux of style and textile design.

The result of the MFC is the large number of products produced in small lots and broadly distributed. Its life cycle is very short due to the demands of consumers innovative products in times dwindling.

The product fashion clothing is developed from surveys fashion trend and can be ranked among commodities and diversified. The commodities products have a lot of products equal, differentiated only in the colors and patterns (Figure 2), while the diversified products have diverse forms and volumes unequal among themselves, and may be differentiated by colors and patterns (Figure 3).

Figure 2 - Commodities. Source: MFI (2005)

Figure 3 - Diversified Products. Source: MFI (2005)

According to Mendes (2010), the tend to commodities products (Figure 2), are distinguished by having scale production of a large number of pieces only differentiated by the colors and patterns of the fabric. Already diversified product are present in the mix of product in the collection (Figure 3), have characteristics of innovation, shapes and little volumes and aim to meet the fashion trend of a certain period of time (weather station).

The importance of product differentiation is described by fashion Lipovestsky (1989, p.32) "... is not that the fashion is not known equally true innovations, but they are much rarer than the succession of small changes of detail. It is the logic of minor changes that characterizes proper fashion; ... ".

7. Solid Waste in MFC

Solid wastes are wastes in solid and semi-solid state resulting from industrial activities, domestic, hospital, commercial, agricultural, service. According to ABNT NBR 10.004:2004, are included in this definition the sludge from water treatment systems those generated in equipment and pollution control facilities.

The National Policy on Solid Waste (PNRS) regulates the collection, treatment and final destination of urban waste, hazardous and industrial, among others The law establishes important goals for the sector, such as the closure of landfills by 2014.

The implementation of environmental laws and regulations increasingly restrictive and creating more competitive markets are demanding that companies MFC are more efficient in production and environmental terms. The increase in industrial production should be coupled with a lower consumption of inputs and the generation of pollutants.

Organizations have established procedures to identify the environmental aspects of its activities, products or services that may be controlled by it, in order to determine those which have or can have significant impacts on the environment. For each environmental aspect is associated with at least one environmental impact, which can be defined as any change in the physico-chemical and / or biological environment due to any form of matter or energy generated by human activities (BASTIAN and ROCCO, 2009).

Different authors as Bastian and Rocco (2009), Berlin (2009), Rodrigues et al (2006), Santos (2007), Pires et al (2005) reported the main environmental impacts of the textile sector:

a) Generation of wastewater and color: mainly through the stages of textile finishing executed in laundries, dry cleaners and stamping industry, changing the look and textures of yarn, fabrics and products with the aim of adding value.
b) Scent oil Enzimage: with the heating occurs volatilization of oils Enzimage and the vapors are discharged to the atmosphere and generating strong smell. These oils are used to lubricate the threads of textile fibers, natural or synthetic in order to increase the cohesion of the fibers and assist in sliding the wire guides and machinery.
c) Generation of waste: along the textile chain there are several operations that generate waste from ginning up leftover yarn and woven garments generated in clothing, varying these tailings as well as characteristic and quantity.
d) Noise and Vibration: various equipment used in the successive steps of the textile chain can be a potential source of emissions of noise and vibration, which if not controlled can cause nuisance to the neighborhood of industries.
e) Power consumption: fossil fuel use in the agriculture sector, the machinery used to heat boilers washing and dyeing in general, the machinery for the production of: yarns, fabrics, garments and accessories production.
f) Water consumption: water is a key resource that see being operated improperly. Especially in the use of irrigation in cotton fields, but also in sectors dyeing, finishing textile.
g) Use of toxic products: besides the use of powerful chemicals in the fields of bleaching, dyeing and printing, one should consider in particular the use of pesticides and pesticides in traditional cotton monoculture, causing diseases in farmers and degrading the soil and groundwater.

For Fletcher (2011) all professionals involved in the development and production of fashion garments, designer's technical staff, including the cutting department should collaborate with suggestions to promote waste reduction. The Cutting department is responsible of the study fitting parts modeling along the width of the fabric, this study aimed at maximizing the use of the fabric. The next step is the organization of overlapping layers of fabric with the aim of promoting a single cutting action, the result is a large volume of cut pieces of the same product. The main steps of the process of making clothes are described in the flow chart (Figure 4). In it are described the steps, the main raw materials and the main waste generated.

Presented in the flow, most of the steps generate solid waste to a lesser or greater amount. The largest solid waste generator is the step-cut.

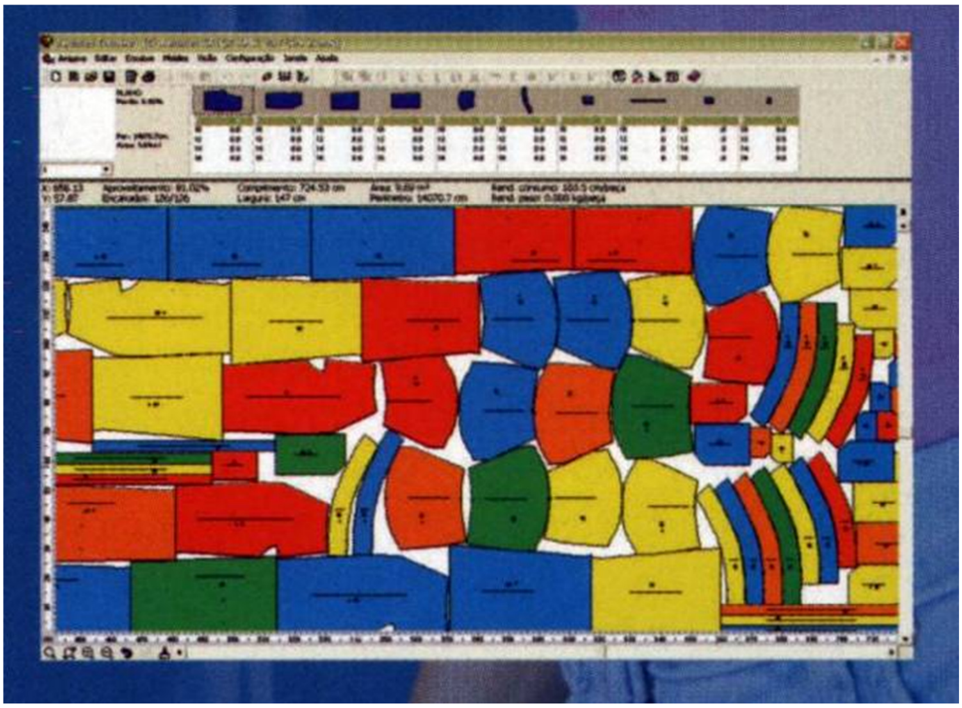

Figure 4 - Study fitting parts computer modeling Source: Advertising Materials (2010)

The blank refers to the planning of the product created, that is, the reproduction of parts of the garment in planes that can be represented by paper or computer screen. The shapes of molds attached to the ergonomics of the human body (trunk, arms, legs, neck), resulting in parts which must be covered (cut off). As an example of mold parts of a shirt, there are parts of the front, back, sleeves, cuffs, pockets and collar, which in turn is composed of standing collar, collar, etc..

The study of fitting parts modeling also aims to reduce the amount of solid waste in manufacturing. The cutting department is the environment in which there is the largest volume of solid waste textiles. Other types of waste are generated by other steps in the production process of MFC, such as effluents from processing industries, laundries and dry cleaners that at this time, are not the object of study in this article.

At the end of the production process, in addition to the expected products, there is a greater or lesser amount, the production of solid waste. One of these solutions can be effective to minimize the negative effects caused by waste are concepts of 5 Rs

8. Concepts of 5 Rs

According to Fatah (2007) concepts of 5 Rs are: rethink, reduce, reuse, repurpose and recycle. All concepts, if used properly, result in saving water, energy, time and materials used in the production of these products or materials.

a) The concept of Reduce: reduce consumption is important for the purpose of restricting the waste by buying only what you need and the amount required. Buy durable products or raw materials with long life cycle. It is important to check whether the packaging is reusable or returnable. Increasing the amount of product for packing and reduce as much as possible the packaging material feedstock or product.

b) The concept of Reuse: It is important to note that the packaging is reusable or recyclable. It is important to repair and renew materials or objects, do not consume disposable products or raw materials. Should save materials and objects appropriately for later use and donate to whom it may concern objects, materials to be reused.

c) Concept of Repurpose: it is important to use packaging textiles materials and products that can be used to pack other objects or materials or own trash. It is crucial when buying products, choose those whose packaging may be intended for other uses. Buy textiles that can be renewed from dyeing to give a new destination to materials and objects.

d) Concept of Recycle: through a new production process waste in the form of materials or products, can be transformed into a new product or raw material to initiate a new cycle of production-consumption-disposal.

e) Concept Rethink: you need to stop to reflect and see the real need for that type of product or raw material. The durability of the product should also be taken into account. It is important to know if the raw material is polluting, the fate of the product after use and if it is possible to reuse after use of the raw material or product. It is important to know the fate of disposal and what is the origin of the material or product. All these analyzes and reflections result in a more conscious consumption.

1° moment (yesterday)	2° moment (today)	3° moment (tomorrow)	Observations
3Rs.	**5Rs.**	**7Rs.**	**Wanted**
1 – Reduce	1 – Reduce	1 – Reduce	What is more important?
2 – Reuse or repurpose	2 – Reuse	2 – Reuse	Reinventing a new way of:
3 – Recycle	3 – Repurpose	3 – Repurpose	– to live
	4 – Recycle	4 – Recycle	– to consume
	5 – Rethinking	5 – Rethinking	– to produce
		6 – Refuse	– to transport
		7 – Recover	– to store
			– to provide financial services

Table 2 - Evolution of Rs Source: Fatá (2007)

According to Fatá (2007) Evolution of Rs is shown in Table 2. Were initially considered only the first three Rs: Reduce, repurpose / recycle and reuse. Today practicing the 5 Rs but, for the future, it will be important to the addition of two more Rs: Refuse or fail to consume and recover everything that can be redeemed in order to reinvent a new way to develop new products, consuming materials and produce goods and services.

9. Case Studies

In order to understand the application of 5Rs in MFC, were surveyed three companies, being a service provider company sewing (GM), a spinning and weaving (ES) and a fashion label (SL).

The brand new GM develops its products from manufactured products left over in stock. Are products of fashion garments designed and produced in knitted fabric of the highest quality for leading international brands.

A partnership was established between Brazilian designer and a manufacturing company of fashion garments (manufacturing). The brand offers pieces with small defects or excess production, as well as fabrics and trimmings left over in inventory and waste generated in the production and the stylist will use these materials as inputs for a new creation and production of fashion garments. The stylist with creativity, and applying fundamentals of fashion trend, renews the textile developing a new collection. The goal of this project is to develop new products without purchasing new materials.

ES is a weaving company that produces high quality fabrics, since the year 2004 and made possible through an alliance with textile companies and the community. The ES produces new wires from textile waste generated by cutting departments of companies MFC (manufactures).

The ES collects leftover fabrics in clothing and forwards them to small cooperatives that are responsible for separating waste for color and materials. Once cataloged, the ES submit materials to grinding, shredding and cleaning and other different processes, all free of any chemical. Following is the stage of preparation for a new spinning process and production of woven or knitted.

The SL is a brand of fashion clothing that develops two major collections, and other, small collections and these depend on the needs of the market. Throughout its existence has always had as its style, fashion products daring and innovative for a different audience.

During the study of fitting of parts modeling, the designer creates decorative elements for some new products. These elements can be, for example, small pockets that are developed from the spaces between the pieces of necklines and armholes, or may be new accessories such as purses and necessaries, depending on the size of the spans between a mold and other. The remaining residue is separated into boxes according to the nature of the raw material fibers. Such wastes are intended for industries that produce materials crumbles and felted or fillers for pillows and upholstery.

10. Analysis and Conclusions.

It is noticed that the concepts of 5 Rs were fully utilized in the three companies starting fashion design, with the goal of creating new products within the characteristics expected by consumers of fashion.

The result of the GM company is the transformation of solid waste generated by the production process of MFC and rejection of defective products or does not meet specifications.

The GM company apply all concepts of 5 Rs The concept for Rethinking is applied to create a product reusing and repurposing ready products or products of surplus production, scraps of fabric and trimmings collection. The concept of Reducing arises at the time that the designer uses parts and materials that are in storage that can be clothes, fabrics and other products previous collections and trims exceeded. The concept for Recycling occurs with the use of waste generated by cutting to create new products such as accessories and other visual elements that modify or complement the decor of the product or fashion clothing.

The ES company applies the concepts to rethink when it receives the waste from cutting department source other clothing manufacturers to create new yarns and fabrics. The company recycles wastes and scraps of fabrics. When the ES company creates a new design for the wires to be used in the design of new tissues and results in reducing the volume of solid waste, is to applied the concept of Rethink. The company uses fabrics that were not acquired by the market to create new accessories such as handbags and hats. The scraps of yarns that were left in production are also recycled to the design of other tissues, handkerchiefs and scarves for example.

For the SL company concepts are applied during the study fitting the mold parts, observing the dimensions of the openings between each mold part. Designers rethink a new decorative element to the creation of new models such as pockets, ruffles or develop different models of accessories like bags and necessaries. The rest of the waste is adequately packed in accordance with the fibers of the raw material, such as cotton, rayon, polyester, polyamide, etc. Then, the material is brought to the industries that fray fabric to be further processed into yarns according to the new spinning process, or for the production of upholstery felts and fille Rs.

It is clear, therefore the design is favoring the concepts of 5 Rs as a way to control the disposal of solid waste and assuming an important role as one of the essential tools in the fight against environmental degradation.

References

ABNT - Associação Brasileira de Normas Técnicas, Resíduos Sólidos – Classificação. NBR 14004. ABNT 2ª. Ed. 2004. Disponível em <http://www.aslaa.com.br/legislações/NBR%20n%2010004-2004.pdf> acesso em 11-12-2012.

BASTIAN, E.Y.O; ROCCO, J.L.S. Guia Técnico Ambiental da Indústria Têxtil. São Paulo: CETESB:SINDITÊXTIL,2009. Disponível.em: <http://www.inovacao.usp.br/APL/pdf/docs/guia_textil.pdf.> Acesso em 10-dez-2012.

BERLIN, L.G., Moda, a possibilidade de leveza sustentável: tendências, surgimento de mercados justos e criadores responsáveis. 2009. 145 p. Dissertação (Mestrado em Ciência Ambiental) – Universidade Federal Fluminense – Instituto de Geociências. Niterói. Rio de Janeiro.

CONTADOR, T. C. Modelo para aumentar a competitividade industrial. São Paulo: Edgar Bhicher, 1996.

FATÁ, R. M., Os Conceitos Básicos sobre Lixo - Os 5 R's. publicado em 10-abr-2007 <http://www.educacaopublica.rj.gov.br/biblioteca/meioambiente/0013.html> Acesso em 20-fevereiro -2013.

FLETCHER, K. GROSE, L., Moda e sustentabilidade: Design para mudança. São Paulo: Editora Senac, 2011.

GODOY, A. Introdução à pesquisa qualitativa e suas possibilidades. Revista de Administração de Empresas, v.35, n2, p.57-63, mar./abr. 1995.

HORTE, S.A., LINDBERG,P., TUNALV,C. Manufacturing Strategies in Sweden, Int. J. Prod. Res., vol.25, n.11, 1987.

IEMI, Instituto de Estudos e Marketing Industrial. Relatório Setorial da Cadeia Têxtil Brasileira. São Paulo: Free Press, 2012.

IFM, Institutut Francais de La Mode, Catálogo de Formandos, 2005.

KOTLER, Philip & ARMSTRONG, Gary. Princípios de Marketing. Rio de Janeiro: LTC, 2000.

LAKATOS, E.M., MARCONI, M. de A. Fundamentos de Metodologia Científica. 7ª ed. São Paulo: Atlas, 2010.

LIPOVETSKY, G., O Império do Efêmero: A Moda e seu Destino nas Sociedades Modernas. São Paulo: Companhia das Letras, 1989.

MENDES, F.D. Cadeia Têxtil e as Estratégias de Manufatura na Indústria do Vestuário de Moda, dissertação de Mestrado do Departamento de Pós-graduação da Universidade Paulista, São Paulo, 2006.

MENDES, F.D. Um estudo comparativo entre as manufaturas do vestuário de moda do Brasil e da Índia. Tese de doutorado em Engenharia de Produção pela Universidade Paulista – UNIP, 2010.

MENDES, F.D., SACOMANO, J.B. FUSCO, J.P.A. Rede de Empresas: A Cadeia Têxtil e as Estratégias de Manufatura na Indústria Brasileira do Vestuário de Moda. São Paulo: Arte & Ciência, 2010.

PORTER, M. E. Competição : Estratégias Competitivas, 7ª. Ed. Rio de janeiro: Campus, 1999.

PORTER, M.E. Estratégia Competitiva. Rio de Janeiro: Campus, 1986.

RECH, S. R. Moda: por um fio de qualidade. Florianópolis: Editora da UDESC, 2002.

RENFREW, E. RENFREW, C. Desenvolvendo uma coleção. Porto Alegre: Bookman, 2010.

RODRIGUES, S.C.; PEIXOTO, J.A.A.; XAVIER, L.S. Gestão Sustentável de Resíduos Industriais: Um Exemplo de Cadeia Verde de Suprimentos no Setor de Reciclagem. In: VII Congresso Nacional de Excelência em Gestão. CNEG 2011. Rio de Janeiro.

SANTOS, A. L. T. dos. A relação entre o luxo e a sustentabilidade ambiental. 2010. 156p. Monografia (Design de Moda e Tecnologia) – Universidade Feevale. Novo Hamburgo. Disponível em:< http://ged.feevale.br/bibvirtual/Monografia/MonografiaAlexandraSantos.pdf>. Acesso em: 9-out-2012

SLACK, N.; CHAMBERS, S.; JOHNSTON, R. Administração da Produção. 2. ed. São Paulo: Atlas, 2002.

SORGER, Richard; UDALE, Jenny. Fundamentos do Design de Moda. Porto Alegre: Bookman, 2009.

SOUZA, G. de M. O Espírito das Roupas: A Moda no Século Dezenove. São Paulo: Schwarcz, 1987.

TUTIA, R. A Gestão da Cadeia de Suprimentos e o Outsourcing como Estratégia da Manufatura do Vestuário de Moda. Dissertação (Mestrado em Engenharia de Produção – Universidade Paulista, São Paulo, 2008.

YIN, Robert K. - Case Study Research: Design and Methods (Applied Social Research Methods), 4a. ed. USA: Sage Publications Inc., 2008.

Nurturing Emerging Industries through Business Ecosystems: *The Evolutionary Processes and Key Building Blocks*

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Abstract
This paper argues that the current literature on business ecosystem theories mainly focuses on established industries from firms' perspectives, while the detailed evolutionary process of how the business ecosystem emerged from the very beginning is absent. Aiming to push the theoretical boundaries further to emerging industries using exploratory case studies on the emerging Electric Vehicle (EV) sector, this paper takes a holistic approach and put forward a conceptual framework asserting that: a Business Ecosystem has four key building blocks including *Resources Pool (RP)*, *Value Networks (VN)*, *Interaction Mechanisms* (between RP & VN), and *Business Contexts (BC)*. This conceptual framework seeks to enrich the understanding of the evolutionary process as well as the detailed interactions between business ecosystem players along the ecosystem lifecycle.

Key Words: Emerging Industries, Business Ecosystems, Electric Vehicle Industry

1. Introduction
During the past few decades, business ecosystem theories have emerged that scholars conducting research within this field are increasingly vocal in the proposition that the competitiveness and survival of firms are not only determined by their internal capabilities, but also by the comprehension of their position within their business ecosystem. From reviewing the literature, it is evident that the study of business ecosystem has mainly been focusing on established industries from firms' perspectives, while the detailed dynamic process of how the business ecosystem emerged from the very beginning is absent. Employing exploratory case studies from the emerging Electric Vehicle (EV) industry, this paper takes a holistic approach and put forward a conceptual framework that pushes the theoretical boundaries of business ecosystem theories to emerging industries' development. This conceptual framework seeks to enrich the understanding of the evolutionary process as well as the detailed interactions between business ecosystem players along the ecosystem lifecycle.

2. Literature Review

Definition of Business Ecosystem

Moore originally proposed the concept of business ecosystem in 1993. He defined the term as *"An economic community supported by a foundation of interacting organizations and individuals- the organisms of the business world. This economic community produces good and services of value to customers, who are themselves members of the ecosystem. The member organizations also include suppliers, lead producers, competitors and other stakeholders. Over time, they co-evolve their capabilities and roles, and tend to align themselves with the directions set by one or* *more central companies."* Figure 1 depicts well the static view of Moore's business ecosystem (Moore 1996). In Moore's view, the term business ecosystem not only encompasses the core supply chain and extended enterprises but also envelopes other stakeholders such as industrial associations and the government. More importantly, it is stressed by the founder of business ecosystem theory that the co-evolution and interaction among these different level of organisations including firms within the supply network, extended enterprises and policy makers are critical for their co-development.

Since Moore's proposal of the business ecosystem concept, many scholars have endeavored to define the term since 1993. Summarising the definitions given to the term business ecosystem in Table 1, the working definition of the term business ecosystem is said to be "**a community consisting of different levels of interdependent organisations, who are loosely interconnected and generate co-evolution between partners and their business environment**".

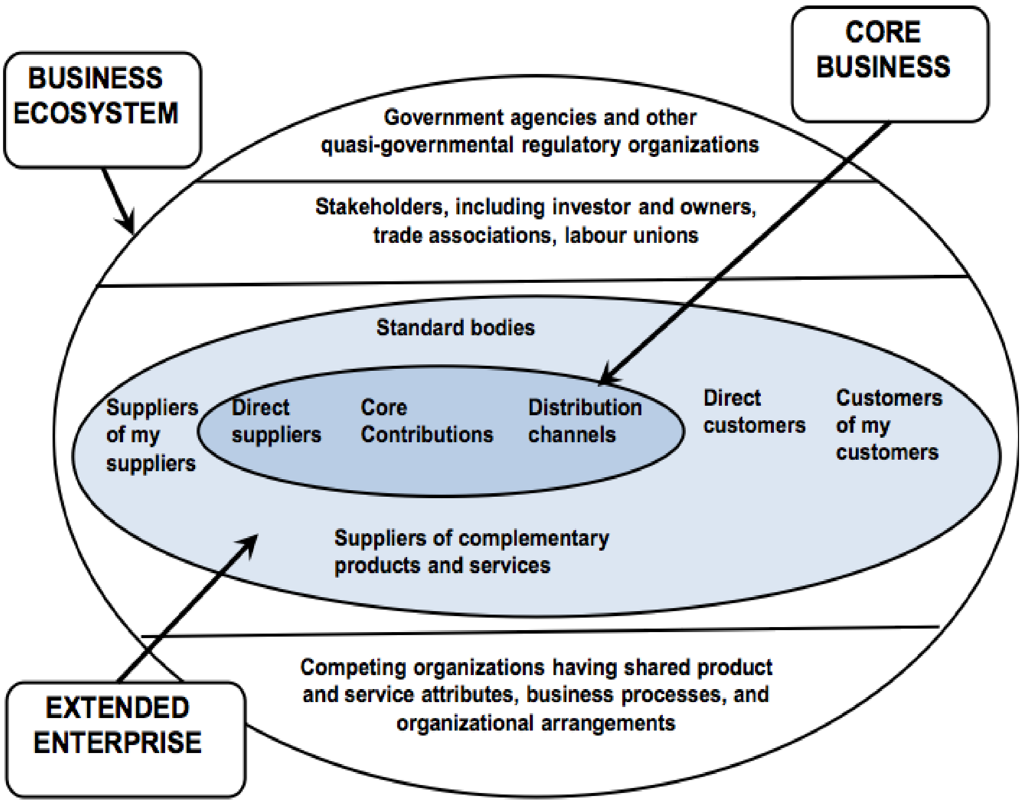

Figure 1 Static view of a business ecosystem (Moore 1996)

The loosely interconnected feature is emphasised as a number of papers have stressed the importance of many "loosely interconnected" members who rely on one another to survive and acquire mutual advantages within a business ecosystem (Isanti & Levien 2002, Isanti & Levien 2004b, Peltoniemi & Vuori 2004)."

Year	Author	Business Ecosystem & its Related Concepts' Definition	Defining Keywords & Phrases	Case Industries
1993	Moore	Business Ecosystem: An economic community supported by a foundation of interacting organisations and individuals - the organisms of the business world. This economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisations also include suppliers, lead producers, competitors, and other stakeholders. Over time, they co-evolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies.	Interacting organisations, co-evolve, align	Personal Computers, Consumer Electronics, Information and Communication, Biotechnology, Retail and Automotive Industries
2001	Power & Jerijian	Business Ecosystem: A system of websites occupying the world wide web, together with those aspects of the real world with which they interact. It is a physical community considered together with the non-living factors of its environment as a unit	Interact, community, environment	E-Business, Aerospace, Computer Electronics and Chemical Industries
2002	Kraemer & Dedrick	Business Ecology: A broad community of firms and individual that add value to a technology standard by supplying complementary assets to the core products	Community, add value	IT Industry
2003	Manning & Thorne	Ecosystem of Demand: A complex grouping of companies and customers, suppliers, and partners that gain mutual benefit from one another.	Complex Grouping, Mutual Benefit,	Finance, IT and Retail Industries
2004	Isaniti & Levien	Business Ecosystem: A business ecosystem is a business network, which are formed by large, loosely connected networks of entities, that interact with each other in complex ways, and the health and performance of a firm is dependent on the health and performance of the whole	Loosely connected networks, interact, dependent	Computer Electronics, Apparel, Biotechnology, Retail and Energy Industries
2004	Peltoniemi & Vuori	Business Ecosystem: A dynamic structure which consists of an interconnected population of organisations. These organisations can be small firms, large corporations, universities, research centres, public sector organisations, and other parties which influence the system.	Dynamic structure, interconnected	N/A
2005	Quaadgras	Business Ecosystem: A set of complex products and services made by multiple firms in which no firm is dominant.	Complex, Multiple firm	High Tech Industry (RFID)
2006	Adner	Innovation Ecosystem: The collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution. Innovation ecosystem has become a core element in the growth strategies of firms in a wide range of industries.	Collaborative arrangements	High Tech Industries
2006	Gueguen et al	Business Ecosystem: based on the idea that several companies will collaborate to improve their offer; importance of leadership, the role of "keystone organisations", the principle of co-evolution.	Collaborate, coevolution, keystone organisations	Software Industry

2006	Adomavicius et al.	Technology Ecosystem: emphasizes the inherently organic nature of technology development and innovation that is often absent in standard forecasting and analytical methods.	innovation	Electronic Industry
2006	Isaniti & Richard	IT Ecosystem: comprises the large number of organizations that influence the value of IT products or services, which "depend on each other for their mutual effectiveness and survival. The list includes microprocessor companies, such as Intel and AMD, other semiconductor component providers, such as Samsung and nVidia, computer system providers, such as HP, Dell, and Apple, software providers, such as Microsoft, Intuit, and SAP, and system integrators, such as Accenture and Cap Gemini. Some firms compete in many different ecosystem segments, such as IBM, which provides hardware (e.g., X Series servers), software (e.g., Websphere), and services (e.g., IGS, or IBM Global Services).	Depend on each other, mutual effectiveness, survival	IT Industry
2008	Chang & Uden	Business Ecosystem: A network of buyers, suppliers and makers of related products or services and their socio-economic environment that includes institutional and regulatory framework.	Network, environment	E-Learning Industry
2009	Li	Business Ecosystem: move beyond market positioning and industrial structure by having three major characteristics: symbiosis, platform, and co- evolution	Symbiosis, Platform, Co-Evolution	IT Industry
2009	Dourmas & Nikitakos	Business Ecosystem: A dynamic structure which consists of an interconnected population of organizations. These organizations can be small firms, large corporations, universities, research centers, public sector organizations, and other parties which influence the system. In different texts, business ecosystem is defined either consisting of several organizations or of only one organization. In the latter, individual organization should operate as an ecosystem, in order to survive. Business ecosystem develops through selforganization, emergence and co-evolution, which help it to acquire adaptability. In a business ecosystem there is both competition and cooperation present simultaneously.	Interconnected, selforganiztion emergence, coevolution, adaptability, competition, cooperation	Maritime Industry
2011	Rong	A business ecosystem is a community consisting of different level of interdependent organisations, who generates co-evolution between partners and their business environment.	Community, Interdependent, Coevolution, environment	Mobile Computing Industry

Table 1 **Summary of Definitions of Business Ecosystem and its related Concepts**

Ecosystem and its Varied Analogies

In the same way as other branches of ecosystem study, business ecosystem has its roots in biological ecosystem which has the following definition according to the World Resources Institute (2000): "*ecosystems are not just assemblages of species,* *they are systems combined of organic and inorganic matter and natural forces that interact and change*". As a matter of fact, the notion of biological ecosystem has been applied widely in a spectrum of research fields, namely industrial ecosystem, social ecosystem, digital business ecosystem and economics bionomics (Peltoniemi and Vuori, 2004). While industrial ecosystem as an analogue of the biological ecosystem is chiefly concerned with environmental conservation that the ultimate aim of such is to reuse the materials with efficiency (Frosh and Gallopoulos, 1989), the social ecosystem stresses the vision that "each organisation is a fully participating agent which both influences and is influenced by the social ecosystem made up of all related businesses, consumers, and suppliers, as well as economic, cultural and legal institutions" (Mitleton-Kelly, 2003). Regarding the digital business ecosystem, its objective is to increase the chance for SMEs within Europe to rival with bigger organisations by offering a structure in which software made by SMES is able to behave in a way similar to organisms in an ecosystem (Nachira, 2002). Hence, despite the term also encompasses the word business, it is not associated much with business ecosystems. From another perspective, Rothschild (1992) views the economy as an ecosystem that in his interpretation of economics bionomics, biological organism defined by its genes and its relationship with its preys and competitors is equivalent to firm defined by its technology and its relationship to suppliers, customers and competitors. According to Rothschild, the economy is regarded as an ecosystem with firms acting as biological organisms while industries serving as species.

The Evolutionary Stages of Business Ecosystems

Dynamically, the life cycle of a business ecosystem includes the phases of birth, expansion, authorities and renewal (Moore, 1993). In the first stage of birth, firms work in collaboration to identify new value proposition surrounding a new invention. Once the business ecosystem reaches its second stage, the market expands with participants cooperating with each other to increase the level of production while at the same time trying to get hold of the key market segments in the fierce competition between suppliers. In the next stage of authorities, the business ecosystem is consolidated such that the leaders within the ecosystem decide the ways in which participants are incentivised to collaborate with one another. In the last stage of renewal, the already matured business ecosystem is vulnerable due to the innovative ideas arising from the emerging business ecosystem. At this point, the death of the mature ecosystem may occur if the leaders do not adapt and amalgamate the new invention into the established ecosystem.

Adapting from Moore, Rong enriched the business ecosystem life cycle concept with five phases of emerging, diversifying, converging, consolidating and renewing as the evolutionary pathway of the ecosystem using cases studies from the semi-conductor industry (Rong, 2011). This is illustrated in Figure 2 along with the demonstration of the nurturing process in each stage. On top of this, Rong has identified the constructive elements and configuration patterns along the each phases of the business ecosystem evolutionary pathway. In particular, the constructive elements consist of functional role, solution platform, adaptive solution, extended resources, new vision development, relationship governance, core business process and enabling mechanism development. The constructive elements are derived on the theoretical basis of the structure and infrastructure model (Hayes & Wheelwright 1984) that the constructive elements play a key part in influencing the configurations of business ecosystems (Rong 2011).

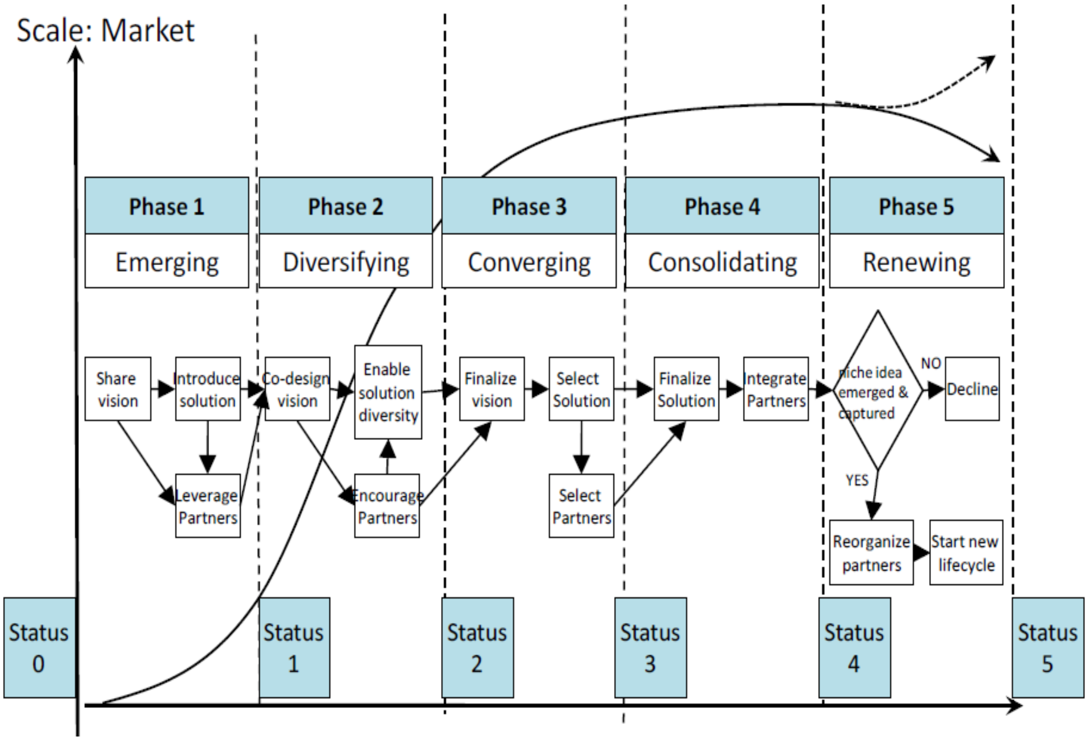

Figure 2 : Business Ecosystem life cycle and its nurturing process (Rong 2011)

Business Ecosystem Health & Players

Based on Moore's ecosystem, Isanti and Levien identified four categories of players which are the keystone player, the niche player, the dominator and the hub landlord who are participating within the ecosystem, such that the functions and strategies of these players are pinpointed accordingly (Isanti & Levien 2002, 2004b). Isanti and Levien contend that the task for the keystone player is to provide a platform allowing other participants to work and collaborate with one another (Quaadgras 2005). For niche players, they aim to progress their specialized capabilities in certain spheres so as to create more value for the business ecosystem. The dominators on the other hand manipulate the main segments of the network while enjoying the majority share of the value through vertical or horizontal integration. Concerning the hub landlords, they seek to obtain the greatest possible benefit they could acquire from the ecosystem while not managing the system in any straightforward manner.

In addition, three parameters are used in examining the fitness level i.e. the health, of the business ecosystem, namely the levels of productivity, robustness and niche creation (Isanti & Levien 2004b). The two scholars assert that productivity is "*a network's ability to consistently transform technology and other raw materials of innovation into lower costs and new products.*" Robustness refers to the capability of a business ecosystem when they are "*facing and surviving perturbations and disruptions*", which implies that it is testing whether or not the ecosystem is able to endure the dynamic shift of its surrounding environment. Regarding niche creation, it is questioning the level of variation of companies and products within the ecosystem so as to test its health. For assessing the level of productivity, measures of total factor productivity, productivity improvement over time and delivery of innovation are used while survival rates, persistence of ecosystem structure, predictability and limited obsolescence are prescribed as the examining factors for robustness. Last but not least, the aspects of variety and value creation are employed for determining the level of niche creation as a parameter in understanding the health of business ecosystems.

	Keystone Player	**Dominator**	**Hub Landlord**	**Niche Player**
Definition	Actively improves the overall health of the ecosystem and, in doing so, benefits the sustained performance of the firm	Integrates vertically or horizontally to manage and control a large part of its network	Extracts as much value as possible from its network without directly controlling it	Develops specialised capabilities that differentiate from other firms in the network
Presence	Generally low physical presence for its impact; occupies relatively few nodes	High physical presence; occupies most nodes	Low physical presence; occupies very few nodes	Very low physical presence individually, but constitute the bulk of ecosystems where they are allowed to thrive
Example Case Studies	**Microsoft** **Walmart**	**AT&T** **DEC(Digital Equipment Corporation)**	**Enron** **AOL**	**NVIDIA** **IDe(Integrated Development Corporation**

Table 2 Business Ecosystem Players (Summary based on Isaniti & Levien 2004)

Literature Review Discussion: Research Gap Identification

In summary, it is clear that scholars have successfully explained the reasons for companies to thrive or to become obsolete using the business ecosystem concept. Static pictures of business ecosystems have been depicted along with the identification of the various roles of different players interacting within the business ecosystem. With regards to the dynamics of business ecosystems, researchers have distinguished its lifecycle from other lifecycle studies. In fact, business ecosystem lifecycle broadens the concept of product and industry lifecycle due to its dominant emphasis on the cross industries perspective and the co-evolution between different levels of entities of the ecosystem.

However, it is apparent that consensus has not yet been reached among scholars concerning the definition of business ecosystem, and this field of research is still developing at an early stage. In particular, two main issues need to be addressed urgently. Firstly, it is observed that the majority of cases employed in studying business ecosystems are focused primarily on established industries without insights concerning the emerging industries. This issue deserves more attention because the ecosystem concept stresses the interdependence and the co-evolution between players, which is particularly important concerning the development of emerging industries at the very beginning. Secondly, researchers have studied the concept from a firm's perspective rather than taking a holistic approach, that case studies often concentrate on a focal firm and how it utilized well its ecosystem resources and performed outstanding ecosystem strategies. Consequently, the current literature have primarily focused on the business ecosystem of established industries from firms' perspectives, such that the underlying processes and the building blocks required for business ecosystems to develop from the very nascent stage is unexplored. That is to say, snapshots of how firm behaves within its business ecosystem have been taken, but the detailed evolutionary pathways including the emerging processes at the very nascent stages are not yet well understood.

3. Research Question & Research Design

From reviewing the literature and the identification of the research gaps discussed in the previous section, this paper takes a holistic approach in studying the business ecosystem concept and proposes the following research question: ***How could a Business Ecosystem transform from its very nascent stage to an established industrial value network?*** This proposal aims to push the current theoretical boundary from a matured industry focus to the emerging industry level, seeking to capture the detailed evolutionary processes, interactions among ecosystem players and the key building blocks along the transformation pathways of the business ecosystem development.

In order to answer the research questions proposed, the emerging Electric Vehicle (EV) industry is selected because unlike any other emerging products, the emergence of EVs requires heavy infrastructural support and the collaboration between many players across a spectrum of industries i.e. the establishments of charging points. These properties of the EV industry provide a fertile ground for researchers to study business ecosystem concepts, which highlight the importance of the competition and cooperation between ecosystem players.

Concerning the research method, the exploratory and theory building characters of the proposed research point toward case study (Yin 2009). In fact, the justification in selecting case study is related to the complex and embedded nature of the research topic that a holistic and comprehensive examination is required (Eisenhardt & Martin 2000). In order to understand the transformation process of business ecosystems, it is essential to gain deep understanding of interactions not only between the core players of the EV supply chain but also the extended enterprises as well as other supporting ecosystem players. Furthermore, the method of multiple case studies is chosen rather than single case study due to the higher level of robustness along with its ability of generalization (Herriott & Firestone 1983). Moreover, it is important to define the unit of analysis as it specifies the extent to which data are being collected, and it is said to be the projects that concentrates on the development of EVs which are being carried out by the business ecosystems players. These players from all levels of the ecosystem are engaged in the development of EVs through their involvement in the EV projects.

4. Exploratory Case Studies

The Chinese Electric Vehicle Industry

In 2009, China overtook the U.S and became the largest automotive market in the world following the introduction of sales incentive by the central government. This rapid growing market has attracted all the dominant automakers to gain presence within the country and it is projected that the demand for vehicles is to expand further in the long term as car ownership rate is still very low compared with the developed countries. Accordingly, the Chinese government devotes a great deal of attention to the automobile industry and has set the EV sector as one of its main strategic industry in achieving high economic growth. China initiated research and development concerning the EV industry at the beginning of this century. Currently, the emerging EV industry in China is divided into two main domains. At the higher end, traditional automakers are delivering EVs that aims to replace the internal combustion engines. Concerning the lower end of the market, the low speed low speed EVs are being developed indigenously by local people who aim to capture new demand instead of capturing the demand from replacing the internal combustion engines.

The Low-Speed Electric Vehicle Business Ecosystem

At present, the EV sector in Chinese Shandong province characterises the low speed EV business ecosystem classically and is at the forefront in the development of these low speed products. Thriving in its own unique way, the low speed EV industry in Shandong consists of more than 110 companies of which five in electric motor, thirteen in traction batteries, five in electric control system, twenty-two in final assembly with various design houses and component supplying firms, Shandong has developed its own business ecosystem that low speed EVs are produced by these small indigenous firms working in collaboration within the ecosystem.

In 2009, it was observed in Shandong province that more than a hundred thousand EVs are running locally. These micro EVs are typically cheaper at around £3000 with lower maximum speed at approximately 70 kilometers per hour and shorter distance per charge of less than 200 kilometers. Besides the factors of the surge in oil price and environmental concerns, there are several other factors which catalysed the development of the low speed EV business ecosystem in Shandong (Rong and Shi 2011). Firstly, the natural geographical characteristics of flatland and the sound road infrastructure lowered the barriers of capability requirement for EVs allowing the low speed EVs to flourish. Secondly, as the second most populated province but 20th in size, Shandong is very densely populated with a high degree of urbanization. The distance between cities and rural areas is short which creates the demand for shorter distance transportation. Thirdly, the traditional automotive industry in Shandong developed in the 50s means component suppliers of metal, glass, rubber and motor already exist. In fact, the supply chain of EV and traditional vehicles share similarities. When market demand for this low speed EV is present, Shandong is able to establish its own EV business ecosystem rapidly from resources of the traditional automotive sector.

Data Collection

Exploratory case studies were carried out through the implementation of semi-structured interviews as well as on-site plant visits with firms along the supply chain, policy makers and industrial players of the low speed EV Industry in Chinese Shandong Province. An overview of the research activities is shown in Table 3.

Geographical Location	OEMs (Final Assembly)	Traction Batteries	Electric Motor	EV Dealer	Supporting Institutions
Liaocheng	Shifeng			Shifeng Retailer	
Weishan	Incalcu	Realforce			Government

Jinan	Baoya		Huanguan		Shandong Univ.

Table 3: Overview of the Exploratory Case Studies

Shifeng

Shifeng was established in 1993, originally producing agricultural wheel trucks, the firm has expanded rapidly as one of the main tractor suppliers in the country with the production volume of around 1 million vehicles each year. Situated in Zaozhuang, Gaotang Village, Shifeng sits on more than 3,000 acres of production site while recruiting over 30,000 workers. As the market for agricultural vehicles becomes more saturated, the firm identified the rural market need for daily travel as regular trips between local areas are made by local people but fast speed is not necessary due to the short distance involved. A number of other factors causing the manufacturing of the low speed micro EVs include the fact that rural residents do not possess enough funds for the usage of petrol, the discomfort of motorbikes a well as the availability of manufacturing capacity in producing vehicles. Accordingly, Shifeng produces its EV in two categories, one with the maximum speed of 50 kilometres per hour and distance per charge of 120 kilometres selling at £2500, and the other one with the maximum speed of 70 kilometres per hour and distance per charge of 200 kilometres selling at £3200. Both using lead acid batteries, the charging time is around 8 to 10 hours and can be done conveniently at the backyard of homes using normal electric plugs. The cost for one kilometre is only 8 pence which makes these EVs quite popular among the locals. Moreover, because of its robust manufacturing abilities, the EV supply chain of Shifeng is vertical integrated such that it final assembles and produces all components including the control system and the car bodies apart from the battery and motor parts which are outsourced to other firms.

Yet, these EVs do not meet the standards required for obtaining the official license from the central government hence cannot be produced legally. Having a close relationship and supported by the local government however, Shifeng was allowed to sell its micro EVs only within the Gaotang area such that its product cannot be sold or used in other regions in China. Currently, Shifeng is expecting and following the policies from the central government eagerly while working in collaboration with the local government in the commercialization of its low speed micro EVs within the Gaotang region. Furthermore, the researcher also gained opportunity in visiting and interviewing the relevant retailer of Shifeng which act as a selling channel in dealing with the actual EV sales. As the dealer, it is visited by indigenous customers with the sales volume of 5000 in the year 2010. Due to the current regulation limiting the low-speed production, Shifeng is communicating with local policy makers that the EV is labelled as “sightseeing cars” that when the car is sold, the retailer records the relevant personal details for the buyer and pass it on to the traffic control. At the same time, insurance policies have also been put in place for these EVs as a result of cooperation between Shifeng and local insurance organisations. The current warranty for the micro EVs is three months for the battery and one year for the other parts.

Baoya

Baoya is a private OEM company situated in Jinan, the capital city of Shandong province. The firm was founded in the beginning of this century, originally supplying key components such as motor engines to the traditional automotive sector and started producing low speed micro EV in 2008. The products of Baoya range from electric bicycles, electric motorcycle, electric sightseeing EV and electric golf carts to private EVs. At present, the production capacity is around 3000 vehicles each year. As an OEM, Baoya is occupied in the final assembly of its product and the design of electric motors while outsourcing the production of traction batteries, motors and other components to suppliers. In fact, the firm is a keystone player in the low speed micro EV business ecosystem, as a central player establishing the industrial alliance of the EV industry in Shandong, it collaborates closely with many other companies and organisations. For its electric control system, Baoya is working closely with Shandong University, while at the same time launching a joint-venture with JiuZhao to work on the system of power management. Nonetheless, Baoya is facing serious setbacks due to the absence of license required by the government which means Baoya cannot sell its product domestically. Accordingly, Baoya is exploring the foreign market through acquiring the relevant certificate for exporting overseas to Europe, the South American region and the United States. There is a stable demand from the overseas market as communities from these countries accept well the concept of an environmental friendly second car for families. Rather than producing a prudent design, Baoya produce these low speed micro EVs with a fashionable design and better technical performance. In fact, the firm exports 80% of the total product overseas that only 20% is sold domestically to the local government as police patrol vehicles where registration is not obligatory..

Incalcu Electric Vehicle

Incalcu Electric Vehicle is a subsidiary of the Incalcu Group established in 1992. The group originally was the OEM manufacturer for the well- known Fenghuang bicycle brand in the 1960s. Over the years, the firm has expanded its business to many other areas such as electronics and fitness equipment. The historical pathway of its current EV product evolves from the ordinary bicycle, to electric bicycle, then to electric motor bicycles and eventually to the present low speed micro EVs. Located in Jining, Incalcu produces sightseeing EVs, police patrol EVs, golf carts as well as private EVs with demand from both market domestically and overseas in countries such as Finland. For its domestic market, the vehicle runs at the maximum speed of 50 kilometers per hour using lead acid batteries whereas for the foreign market, lithium ion batteries are employed due to environmental regulations from the overseas governments with maximum speed at 60 kilometers per hour. Lead acid batteries are used domestically so as to decrease the cost of production, the EVs sold locally target mainly consumers with the need of convenient short distance travel such as the activity of housewives sending their children to schools. In contrast with Shifeng, the EV supply chain of Incalcu is much less vertically integrated. The firm has good relationships with many suppliers such that many key components are outsourced, although final assembly and the production of lead acid batteries are done within the company. Despite its lack of official license from the central government, Incalcu is supported by its local government like Shifeng therefore allowing it to sell its EVs within the local region.

Realforce

Realforce is firm producing lithium batteries for the EV industry established in 2008. Located in Weishan in Shandong, the company was ready for production within two years of the initial set up and began to produce Li-Mn, Li-Fe and Li-Co batteries in July 2010. These batteries can be consumed in electric bikes, electric motorbikes, EVs as well as power storage. Currently, Realforce is providing lithium batteries used in the hybrid EV Prius by Toyota. With more than two thousand personnel, an investment of £700,000,000 worth was financed by the founder of company who originally was a coal electricity provider and later shifted the attention to the lithium battery sector. The key to the success of the company's transformation is the ability of the founder of Realforce to identify and recruit a number of highly talented and competent people into the firm. At present, the general condition concerning traction batteries within the EV industry also applies to Realforce, the firm admits that it is facing a number of challenges including the issue of uncertainty regarding standardisation guidelines supposedly provided by the government. However, the company is supported strongly by the local government of Weishan such that their cost of the production site is partly subsidised.

Huanguan

Founded in 2008, Huanguan is a research-based enterprise focusing on the development of electric motors for EVs as well as the relating control and battery management systems. Located in Jinan, the core products of the firm are the axial magnetic field disc motor and the energy regenerative braking power system. Being extremely research oriented, huanguan devote most of its attention to the designing and testing of its product outsourcing all manufacturing parts to other firms. The firm is a classic niche player within the EV business ecosystem. Interestingly, Huanguan is completely self-funded without government support such that a total of 120,000,000 RMB was invested into the company. It is established based on the accumulated life income of the founder who was a research engineer within this field. Nevertheless, Huanguan is closed working with the manufacturing firms of the local EV industry and its specialised ability in designing more efficient electric motors for the EV industry is a key to the development of this emerging business ecosystem.

Shandong University

Situated in capital city of Shandong province, the university was established more than a century ago in 1901. Regarding science and engineering associated departments, the university is dedicated and keen in developing its R&D abilities. Two laboratories from the university are currently involved in the development of EVs. The powertrain system laboratory of the department of engineering implements and enhances the performance of the EV powertrain system and is working closely with OEM firms from the EV industry in Shandong. Collaboration with Baoya is frequent such that the firm has requested assistances in the powertrain system of its EV products from the laboratory. Whereas for the battery material laboratory from the department of chemistry, the research centre focuses on the exploration of better anode material for traction batteries so as to ameliorate the current technological challenge of the issue of battery power density. The assisting character of the two research centres to the EV business ecosystem in Shandong is important in its development especially when the ecosystem is at the emerging stage.

Shandong Local Government Office: EITC

The Economic and Information Technology Committee (EITC) in Shandong is the local government office supporting the Ministry of Industry and Information Technology from the central government in China. This local committee works to stimulate the development of emerging sectors while at the same time providing guidelines and assistance to the firms within these industries. Recently, the local government has devoted more efforts to the progression of the EV industry, through setting relevant policies and subsidising firms that manufacture the key sections of EVs such as traction batteries and electric motors as well as OEM companies. The specification of the low speed micro EVs produced locally in Shandong does not meet the official requirement in order to obtain the license by the central government. As the central government is attempting to prevent the manufacturing of these EVs, the local government on the other hand is reluctant to restrict firms as they contribute sizable amount of tax. Therefore, while the local government is issuing policies promoting the ordinary EV industry, the regulations concerning low speed micro EV is ambiguous. This is a major obstacle especially for the development of the EV business ecosystem in Shandong as most of the firms involved in this industry is engaged in the manufacturing of low speed EVs. Concerning the infrastructural support in terms of charging facilities for the EVs of Shandong, the government has invested hugely that the nationally-owned electricity provider, the state grid, is working in collaboration with local companies in 17 cities within the province. In 2010, nine large scaled charging stations were built while 500 charging points were established out of which the largest investment of RMB 20 Million was put in the charging station in LinYi.

5. Rethinking the Business Ecosystem Conceptual Framework

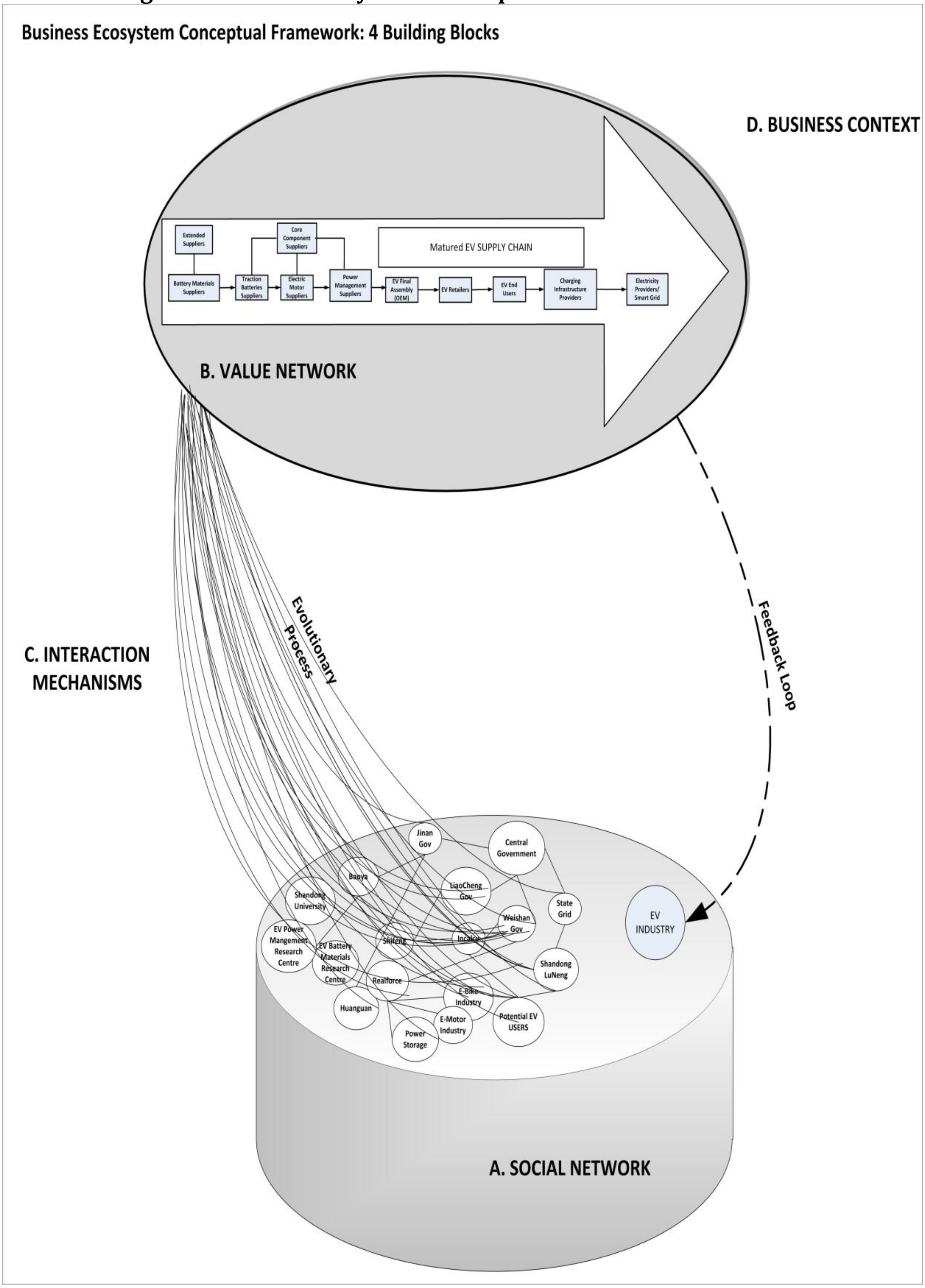

Figure 3: ***Business Ecosystem's Key Building Blocks:***
The Low Speed Electric Vehicles' Business Ecosystem

Following these exploratory case studies, this paper argues that it is necessary for researchers within this field to contemplate an alternative business ecosystem conceptual research framework, as these preliminary data have demonstrated the critical role business ecosystems play in the nurturing of emerging industries. From analysing these data of the emerging EV industry, the new model defining the key building blocks of a business ecosystem is proposed in Figure 3. This papers argues that a Business Ecosystem has four key building blocks including ***Resources Pool (RP)/Social Network (SN)***, ***Value Networks (VN)***, ***Interaction Mechanisms*** (between RP & VN), and ***Business Contexts (BC)***. Differing from the preliminary working definition of business ecosystem in the literature section, this paper put forward the following assertion: *Business ecosystem involves an interdependent and interactive relationship between resources pool/social network and value networks, which are enveloped and affected by their business context*.

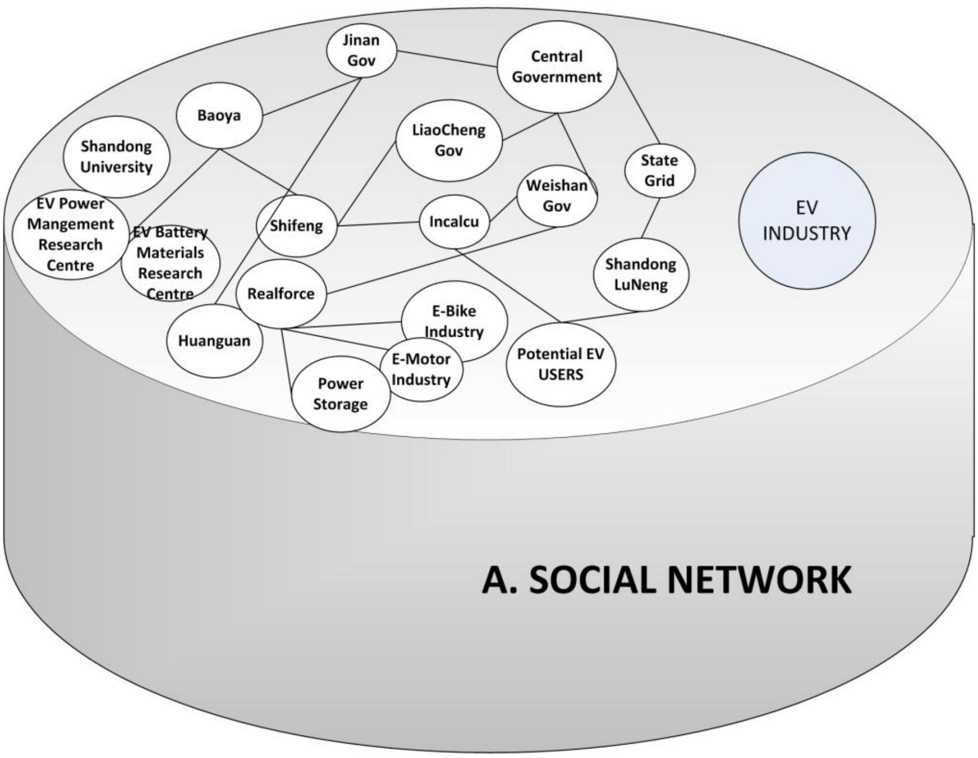

Figure 4. Key Building Block: Resources Pool/Social Network (SN)

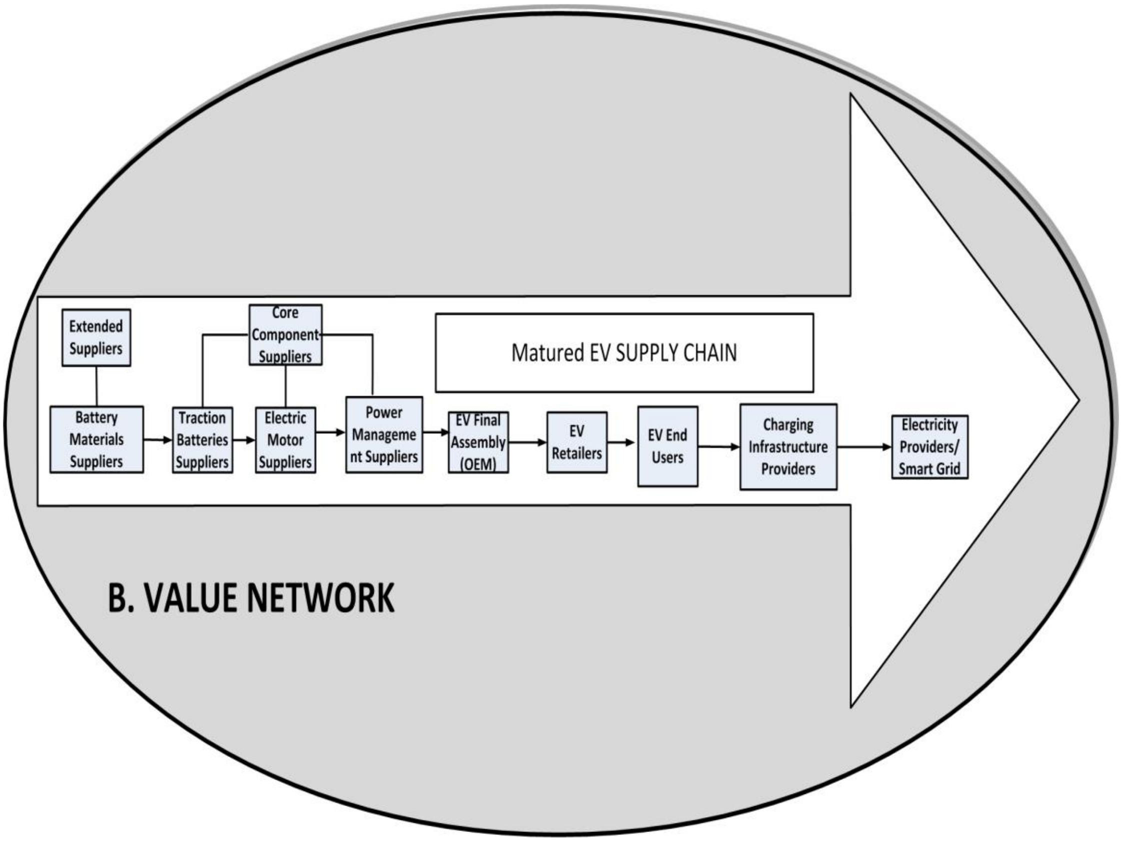

Figure 5. Key Building Block: Value Network

Concerning the four building blocks, firstly, the building block of SN (or Resources Pool)[1] is depicted in Figure 3A, it shows that ecosystem players and their social ties are embedded in this resources pool, stressing the importance of the relationship between players at the nascent emerging stage of industrial development[2]. Secondly, VN is demonstrated in Figure 3B, this part of the business ecosystem has already formed a matured industrial supply chain that the value chain formation process from SN to VN constitutes the third building block IM (Figure 3C). In fact, the Interaction Mechanism has two parts, one part is the ***Evolutionary Processes*** transforming SN to VN; the other is the ***Feedback Loop*** allowing the matured industrial network to contribute back to the resources pool. It is necessary to point out here, that one key difference between RP/SN and VN is that RP/SN initially has no business purpose and no commercial value creation; but VN is a commercial value creation system. Last but not least, the ecosystem is enveloped and affected by the fourth building block (Figure 3D), the Business Context, which includes cultural aspects and elements such as policies. The case studies have highlighted the importance of this fourth building block, that the development of key OEMs: Shifeng, Baoya and Incalcu have been strongly influenced by policies. This implies that even with all the correct building blocks and interacting mechanisms in place, the coevolution between players and successful development of emerging industries cannot take place without the right nurturing context.

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[1] Social Network and Resources Pool both describes the first building block.

[2] Figure 4 and Figure 5 depict a more clarified picture of the building blocks Social Network and Value Network respectively, demonstrating the details in comparison to Figure 3, which provides a macro picture of the business ecosystem conceptual framework.

Business Ecosystem Research: The Next Step
Based on the conceptual framework involving building blocks of RP/SN, VN, IM and BC, this paper proposes the following three areas of research to be conducted concerning business ecosystem theories. First, the building block of RP/SN is to be deconstructed that the detailed interaction between ecosystem players at the very early stage of the emerging industry development should be better understood. Secondly, it is crucial to define the stages of the IM's Evolutionary Process and to map out the detailed pathways transforming RP/SN to VN. In particular, issues such as the coevolution and coadaptation between players and business model identifications, which are embedded within the nurturing process along the IM require heavy attention and close examination. Thirdly, the capabilities of key ecosystem players allowing successful transformation from RP/SN to VN along the Evolutionary Process are to be teased out. The identification of the capability dimensions would not only shed light on the theoretical aspects of business ecosystem research, but also providing practical guidance for industrial players along the development pathways of emerging business ecosystems.

6. Conclusion

To recapitulate, this paper has reviewed the literature on business ecosystem theories and has argued that the current understanding of the business ecosystem concept is still narrow that theoretical boundaries need to be pushed to emerging industries. That is to say, the focus has been primarily on established industries' business ecosystems from firms' perspectives, that the detailed dynamic process of how the business ecosystem emerged from the very beginning is absent. It is true that researchers have endeavored to depict a business ecosystem lifecycle, but only stable snapshots at each stage are put forward lacking details of the evolutionary progress.

Consequently, this paper advocates the rethinking of the business ecosystem conceptual framework, based on the case studies from the emerging electric vehicle industry, this paper proposes the following: a Business Ecosystem has four key building blocks including *Social Networks (SN)*, *Value Networks (VN)*, *Interaction Mechanisms* (between SN & VN), and *Business Contexts (BC)*. It is argued that business ecosystem has an essential function that has been ignored for a long time, which is the nurturing of emerging industries demonstrated in Figure 3. Finally, the next steps of business ecosystem research have been put forward according to this conceptual framework, which aims to not only contribute theoretically, but also providing practical guidance for industrial players along the development pathways of emerging business ecosystems.

REFERENCES

Adner, R., 2006. Match your innovation strategy to your innovation ecosystem. ***Harvard Business Review,*** 84(4), p.98.

Adomavicius, G. et al., 2006. Understanding patterns of technology evolution: an ecosystem perspective. In System Sciences, 2006. HICSS'06. ***Proceedings of the 39th Annual Hawaii International Conference***

Chang, V. & Uden, L., 2008. Governance for E-learning Ecosystem. In Digital Ecosystems and Technologies, 2008. DEST 2008. ***2nd IEEE International Conference*** on. p 340–345.

Dourmas, G& Nikitakos, N. 2009. A new approach to the digital maritime economy. ***European and Mediterranean Conference on Information Systems*** July 12-14

Eisenhardt K, Marin J. 2000. Dynamic capabilities: what are they? Strategic Management Journal: 1105-1121

Gueguen, G., Pellegrin-Boucher, E. & Torres, O., 2006. Between cooperation and competition: the benefits of collective strategies within business ecosystems. The example of the software industry. ***In EIASM, 2nd Workshop on competition strategy.*** p 14–15.

Frosch, R.A. & Gallopoulos, N.E., 1989. Strategies for manufacturing. ***Scientific American***, 261(3), p.144–152.

Herriott, R., Firestone, W. 1983. Multisite qualitative policy research: Optimizing description and generalizability. ***Educational Researcher,*** 12(2),14-19

Isanti, M. & Levien, R., "The New Operational Dynamics of Business Ecosystems: Implications for Policy, Operations and Technology Strategy," ***Cambridge, Massachusetts: Harvard Business School Working Paper***, 2002

Iansiti, M. & Levien, R., ***The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability*** , Harvard Business Press, 2004

Iansiti, M. & Richards, 2006. Information Technology Ecosystem: Structure, Health, and Performance, ***The. Antitrust Bulletin.***, 51, p.77.

Hayes, R.H. & Wheelwright, S.C., 1984. ***Restoring our competitive edge: Competing through manufacturing,*** John Wiley & Sons Inc

Kraemer, K.L. & Dedrick, J., 2002. Strategic use of the Internet and e-commerce: Cisco Systems. ***The Journal of Strategic Information Systems***, 11(1), p.5–29.

Li, Y.R., 2009. The technological roadmap of Cisco's business ecosystem. ***Technovation,*** 29(5), p.379–386.

Manning, B. & Thorne, C., 2002. ***Demand Driven: 6 Steps to Building an Ecosystem of Demand for Your Business***, McGraw-Hill Companies.

Mitleton-Kelly, E., 2003. ***Ten principles of complexity and enabling infrastructures.*** Complex systems and evolutionary perspectives on organisations: The application of complexity theory to organisations, p.23–50.

Moore, "Predators and prey: a new ecology of competition.," ***Harvard Business Review***, vol.71, no.3, p.75, 1993

Moore, ***The death of competition***. Harper Business New York, 1996

Nachira, F., 2002. ***Towards a network of digital business ecosystems fostering the local development.*** IBID

Peltoniemi, M & Vuori, E., "Business Ecosystem as the new approach to complex adaptive business environments," in ***Proceedings of eBusiness Research Forum***, Tampere, vol. 20, 2004

Power, T. & Jerjian, G., 2001. ***Ecosystem: living the 12 principles of networked business,*** Financial Times Management.

Quaadgras, A., 2005. Who joins the platform? The case of the RFID business ecosystem. In System Sciences, 2005. HICSS'05. ***Proceedings of the 38th Annual Hawaii International Conference*** on. p 269b.

Rong, K., 2011, ***Nurturing Business Ecosystem From Firm Perspective: Lifecycle, Nurturing Process, Construct, Configuration Pattern***, PhD Thesis University of Cambridge

Rong, K., Shi Y., Hou, J., Ma, R., 2011. ***An Alternative Innovation From Global Automotive and EV (Electric Vehicle) Industry towards Chinese Low-Speed EV Industry: A Business Ecosystem Perspectives*** (working paper)

Rothschild, M., 1992. Bionomics: Economy as ecosystem, Henry Holt & Company.
Wernerfelt, B., (1984), "A resource-based view of the firm", ***Strategic Management Journal***, 5(2), pp. 171–180.

World Resources Institute, 2000. World Resources 2000-2001: ***People and ecosystem: The fraying web of life.*** Report Series.
Available: http://pubs.wri.org/pubs_pdf.cfm?PubID=3027

Yin R.K. 2009 ***Case study research: Design and methods***, Fourth Edition, Sage Publications, Inc

OFFSET PROGRAMMES IN THE INTERNATIONAL DEFENCE MANUFACTURING SYSTEM: ROLE, DYNAMICS, AND EFFECTS

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ABSTRACT

Offset agreements have become a *sine qua non* in the international arms trade. Defence manufacturers face increasingly demanding offset requirements from purchasing countries as a condition to obtain high-value contracts. Subcontracting, technology transfer, co-production, and licensed production are among the preferred forms of offset investment required by purchasing governments. A key objective of these governments is the integration of local producers into the supply chains of offshore prime contractors, resulting in the emergence of new patterns in international defence production and trade. This paper explores the effects of offset on the configuration of the international defence manufacturing system. The research focuses on examining the impact of offset programmes on defence supply chains in the exporting and importing countries, identifying the major challenges that prime contractors and recipient companies face as well as their coping strategies.

Keywords: defence industry, offset programmes, supply chains, international manufacturing.

1. OFFSET: WHAT IT IS AND WHY IT MATTERS

The rising costs of producing modern weapon systems combined with drastic post-Cold War reductions in Western defence expenditures have caused the emergence of a biased international defence market controlled by the demand side. Global defence expenditure dropped from USD 1.51 trillion in 1988 to USD 1.01 trillion in 2001 (SIPRI, 2012),[1] resulting in a contracted market and defence production overcapacity. Defence companies have strived to survive and remain competitive by implementing a series of strategies such as mergers and acquisitions (M&A), international subcontracting, licensing, and joint ventures (Sköns and Wulf, 1994). In particular, M&A have shaped the current structure of the international defence industry: US industry was consolidated into five 'national champions,' namely Lockheed Martin, Northrop Grumman, Boeing, Raytheon, and General Dynamics; and, after much political deliberation, Europe followed a similar path, resulting in the emergence of four large European defence companies, namely BAE Systems, the European Aeronautic Defence and Space Company (EADS), Finmeccanica, and Thales.

Consequently, the international defence market acquired an oligopoly-oligopsony structure[2] that is both atypical and imperfect and to which free market rules do not apply. Under these market conditions, competition among defence manufacturers is intense and purchasing governments, being both oligopsonistic customers and regulators, use these asymmetric conditions to their advantage by requiring offset compensations from foreign defence contractors as a condition of purchase. Because defence prime contractors are largely reliant

[1] Defence expenditure figures are expressed in constant 2010 USD.
[2] The international defence market is an oligopoly because few sellers have the capacity to manufacture complete weapon platforms. At the same time, it is also an oligopsony because demand is concentrated in few countries capable of affording such sophisticated systems of systems.

on export sales to finance rising R&D costs and survive in a fiercely competitive market, they have no choice but to meet offset demands if they are to maintain and increase market shares.

Defence offset can be broadly defined as a mechanism whereby compensatory transactions are required by governments as a condition to acquire military products from foreign vendors, with the objective of maximising on defence expenditure by generating extra economic, technological, and industrial benefits for domestic producers. Offset as a formal compensatory trade practice was first implemented by European countries at the end of World War II to help balance international trade accounts and reduce the high costs that defence imports represented (Neuman, 1985). Indeed, the general economic objective of an offset agreement is to "[impose] performance conditions on the seller […] so that the purchasing government can recoup, or offset, some of its investment" (Udis and Maskus, 1991, p. 152). Thus, offset contracts are usually negotiated at the same time as the primary procurement contract and result in the supplying company placing work for an agreed value with companies in the purchasing country, "over and above what it would have bought in the absence of the offset [requirement]" (Martin and Hartley, 1995, p. 125).

As offset spread to the developing world in the 1970s, it became an instrument of industrial policy, with governments focusing on achieving technological and industrial development objectives in both the defence and civil sectors. Concomitantly, offset continued to be employed by developed countries with the objective of maintaining and enhancing existing defence production capabilities by requiring offshore vendors to subcontract local companies for the supply of key components and subsystems. Importing countries possessing systems integration capabilities also demanded final assembly as offset, thereby compensating local systems integrators for the potential losses that they incurred when a major contract was granted to a foreign company.[3] Since the end of the Cold War, offset requirements have increased in all geographical regions regardless of the economic development level of the recipient states, with both developing and developed countries imposing strict, and often mandatory and legally binding, offset obligations on foreign vendors. To date, approximately 50 countries have official offset policies, while it is estimated that over 100 countries make informal *ad hoc* use of offset in defence acquisitions (Epicos, 2012).

There are three major types of offset: direct, indirect, and semi-direct. Direct offset involves the participation of local recipient companies in the production of the purchased equipment, often in the form of subcontracting, technology transfer, and licensed production. In contrast, indirect offset is discharged in a variety of civil industries and can even encompass commodity trading, although trends indicate that priority is given to manufacturing activities in sectors of similar technological intensity as defence production (CTO Data Services, 2012). Finally, semi-direct offset involves the engagement of recipient industry in the production of defence inputs unrelated to the acquisition that generated the offset obligation. Regardless of typological classifications, the fact is that offset is restructuring the international defence production system. This is because in pursuit of the generation and enhancement of domestic defence production capabilities, purchasing governments predominantly seek offset obligations to be discharged in the form of purchase orders and subcontracting,[4] leading to the relocation of production activity from the prime contractor's country of origin to the importing economy and therefore to the integration of offset recipient companies into international defence supply chains.

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[3] This is particularly the case of European countries requiring offset from US companies.

[4] Between 1993 and 2011 purchase and subcontracting respectively accounted for 37.01% and 21.55% of the value of all offset obligations fulfilled by US companies (US Department of Commerce, 2013).

The demand for and value of offset transactions are increasingly high. The total value of global offset obligations acquired in 2012 amounted to USD 36 billion and offset demand in top markets is forecasted to grow at a compound annual rate of 3.5% between 2012 and 2021 (Frost & Sullivan, 2013). Moreover, it is estimated that the total value of global offset transactions has reached USD 10 billion per year (Epicos, 2012) and the compounded annual value of offset commitments generated between 2005 and 2016 is expected to amount to half a trillion USD (Avascent, 2012). The constant increase in the value of offset obligations is fuelled by unprecedented high levels of defence spending in Asia, as countries in the region aim at extracting high value-added direct and semi-direct offset investments equivalent to up to 100% of the primary contract value. To compound this, defence spending data indicate that the trend is not going away anytime soon, as Western defence companies are becoming increasingly dependent on export sales. Thus, prime contractors and their domestic subcontracting base face serious outsourcing and supply chain challenges, as they have to offshore outsource production and restructure supply chains internationally in order to comply with offset requirements in a variety of countries possessing very different levels of technological and industrial capabilities.

The objective of this study is two-fold: (1) to assess the extent to which the international defence manufacturing system is affected by offset programmes, analysing the dynamics involved, and (2) to examine the mechanisms whereby offset suppliers and recipients address offset-derived supply chain challenges. The paper is based on original fieldwork research and is structured as follows. Section 2 briefly describes the research methodology. Section 3 discusses the major risks and challenges posed by offset. Section 4 examines the impact of offset on prime contractors and their domestic supply chains. Section 5 elaborates on the effects of offset on recipient companies and the barriers they face to effectively integrate into international defence supply chains. Finally, section 5 presents the conclusions.

2. RESEARCH METHODOLOGY

Most studies on offset are narrative case studies based on anecdotal accounts containing little, if any, empirical evidence (see, e.g. Martin, 1996; Brauer and Dunne, 2004). Although a few empirical studies on offset performance have been conducted (see, e.g. Martin and Hartley, 1995; Matthews, 1996; Balakrishnan and Matthews, 2009), they focus on assessing the effects on the recipient economy without examining the long-term impact that offset programmes have on the supplying companies and the international defence production system at large. To date, there are no previous studies addressing the effects of offset on international manufacturing practices and supply chains. Hence, the present study constitutes explorative research and is based on grounded theory, empirically examining the object of study making use of the case of US companies as suppliers and Spanish companies as recipients. The US and Spain were selected as suitable case studies because of the extensive experience that companies the two countries have supplying and receiving offset investments, respectively. US companies are the world's leading defence suppliers and consequently discharge the largest share of global offset obligations,[5] while Spain has consistently implemented a formal offset policy since the 1980s and Madrid has officially acknowledged that offset has been crucial in developing the domestic defence industry and helping local defence companies integrate into global supply chains (Spanish Ministry of Defence, 2000).

[5] The US Bureau of Industry and Security reports that between 1993 and 2011 US firms entered into 830 offset agreements in 47 countries, with the total sale value amounting to USD 122.67 billion, of which 68.25% was offset, representing a total offset value of USD 83.73 billion (US Department of Commerce, 2013).

Empirical data were collected at one single point in time (April – July 2012), but questions addressing the process of change were incorporated in the interviews, giving the study a longitudinal dimension. Quantitative data on the effects of offset on the US industrial base were obtained from reports by the US Department of Commerce, while qualitative data were gathered through structured and semi-structured interviews with offset representatives of two major US defence prime contractors, identified in this study as US Company A and US Company B. Both companies are among the world's top ten defence producers by the value of annual defence revenues (SIPRI, 2011). Data on the effects of offset on recipient companies were collected through surveys and semi-structured interviews with representatives of ten Spanish offset recipient companies in the three military production sectors, i.e. aerospace, naval, and land systems. All the interviewees were actively involved in the management of major offset programmes in the surveyed companies.

The ten sampled companies provide an accurate representation of the Spanish offset experience at large, not least because six of them are the top national offset recipients, having received nearly half of all the offset investment that Spanish industry obtained between 1984 and 2011 (ISDEFE, 2012). Table 1 lists the ten companies, ranked by the value of latest annual revenues.[6] The sample includes the national systems integrator in the aerospace sector (EADS CASA), naval sector (Navantia), and land systems sector (GD Santa Bárbara) as well as their major local suppliers, including Indra, Spain's leading company in the electronics sector. One company in the sample, Electroop, closed operations in 2008. Hence, data on this company were obtained from former offset project managers. Notably, the subcontracting base is mainly composed of firms in the electronics sector. This is because modern weapon platforms are electronics-intensive and therefore the sector supplies critical parts, components, and subsystems.

Table 1: Surveyed Offset Recipient Companies

Rank	Company	Sector	Revenue	R&D Expenditure	Workforce
1	Indra∗	Electronics	2.688 bn.	7.20%	35,730
2	EADS CASA	Aerospace	2.504 bn.	0.60%	7,500
3	Navantia	Naval	1.574 bn.	7.00%	5,500
4	ITP	Aerospace	518.5 m.	9.54%	1,726
5	GD Santa Bárbara	Land Systems	405 m.	1.67%	2,300
6	Amper	Electronics	393 m.	3.21%	1,900
7	Tecnobit	Electronics	56.6 m.	8.1%	349
8	Rymsa	Electronics	30.5 m.	n/a	322
9	Sainsel	Electronics	n/a	n/a	40
10	Electroop	Electronics	n/a	n/a	n/a

Source: Company Annual Reports, 2012. ∗Approximately 40% of Indra's revenue, EUR 1.075 billion, corresponds to international operations and only 59% of the company's workforce is based in Spain.

[6] Revenue and R&D expenditure are expressed in current EUR and percentage of annual revenue, respectively.

3. OFFSET SUPPLY CHAIN RISKS AND CHALLENGES

Defence supply chains are characterised by a strong focus on technology, high manufacturing costs, and long project life-cycles. Vertical integration whereby a single company produced up to 80% of a military platform has become a thing of the past. Today, as a result of clients demanding offset, defence supply chains are global, outsourced, and complex. Production is being distributed across the world and horizontal integration is so widespread that major US defence contractors only produce 30% of the product, while the remaining 70% is outsourced (Reuters, 2012). Thus, the international defence manufacturing system is composed of multi-layered and multi-faceted supply chains integrated by suppliers from various countries interconnected through complex production relations. The place that each company occupies in the production chain depends on its technological and industrial capabilities as well as on its capacity to generate value-added. In general, however, the prime contractor is at the top of the supply chain pyramid and is responsible for systems integration and final delivery to the end customer. First-tier suppliers are located one level below the primes and provide critical and technologically sophisticated subsystems, e.g., engines and electronics systems. Second-tier suppliers supply specialised but less technologically complex subsystems and components. In turn, third-tier suppliers supply raw materials such as metals and composites. Finally, at the bottom of the pyramid, generic suppliers provide basic inputs such as paints, glass, and wiring (Matthews and Parker, 1999).

Although in theory outsourcing assumes the existence of qualified suppliers possessing the necessary production capabilities (Murman et al., 2002), offset programmes imply that companies in the client country are integrated into supply chains to meet offset requirements regardless of competence. Indeed, it is often the case that, unless the importing and exporting countries have very similar levels of technological and industrial development, offset recipient companies do not possess the necessary expertise and capabilities to effectively absorb offset investment and undertake manufacturing of advanced defence products and inputs. Thus, offset eliminates barriers to entry for less competitive and less technologically advanced producers that without government-mandated offset requirements would not have become part of the supply chain. This in turn results in prime contractors having to provide recipient companies with specialised training, technology transfer, and constant technical assistance to turn them into effective suppliers, potentially increasing production costs and lengthening delivery times. In addition, the implementation of offset programmes leads to defence supply chains often having to be restructured as soon as offset contracts are fully served and new obligations are acquired in other countries.

Even though offset might occasionally generate supply chain cost reductions when competitive suppliers are found in importing countries, such benefit might come at the expense of diminished efficiency and increased risks. Indeed, the offset-derived internationalisation of defence supply chains might reduce reliability and be accompanied by supply interruptions and general malfunction risks. Furthermore, the transferring of orders from the subcontracting base in the prime contractor's country of origin to offset recipient companies results in the former regarding the ordering patterns of primes as volatile and dangerous, not least because the fulfilment of offset obligations is often argued to lead to the erosion of domestic defence industrial capabilities and cause substantial losses of highly-skilled jobs in the exporting economy (see, e.g. Wessner, 1998). In effect, a major concern of the US government and subcontracting base is the fact that offset obligations can force domestic suppliers to exit the industry, thereby causing the loss of critical competences and knowledge that are difficult to regain. This in turn decreases the level of defence industrial sovereignty and self-sufficiency, ultimately compromising the capacity for national defence and generating strategic vulnerabilities (Uttley, 2001). It is for this reason that the US government has a firm position against offset, officially regarding the practice as "economically inefficient and market distorting" (US Government, 1990, p. 1).

Supporting this assertion, the US Bureau of Industry and Security claims that offset can be detrimental to the national economy due to the adverse impact that the outflow of offset investment has on the national industrial base by "[displacing] work that would otherwise have been conducted in the United States" (US Department of Commerce, 2013, p. i). From this perspective, any initial advantages obtained from large export sales might be misleading due to unforeseen long-term consequences. Furthermore, it is argued that even if prime contractors occasionally perceive that they are obtaining greater value for money by relocating production to technologically advanced countries offering lower costs, the fact remains that US companies might be creating their own future competition by transferring technology, capabilities, and knowledge to competent foreign producers that did not incur any initial development costs (US Department of Commerce, 2013). In order to determine to what extent this and other concerns materialise, the following section looks at the impact of offset on US companies and the coping mechanisms they implement to tackle adverse effects.

4. OFFSET EFFECTS ON PRIME CONTRACTORS AND THEIR DOMESTIC SUPPLY CHAINS: EVIDENCE FROM THE US

Official data suggest that at the aggregate level offset is not detrimental to the US defence industrial base. While it is true that offset results in some domestic suppliers losing work, the benefits derived from the large export sales that generated the offset obligations have an overall positive effect on the US defence industry. The US Department of Commerce (2003) reports that between 2009 and 2011, the fulfilment of offset obligations by US companies caused the loss of USD 8 billion of what would have been input added by domestic suppliers. At the same time, however, export contracts secured by prime contractors generated USD 21 billion in added US manufacturing inputs, with the most benefited sector being aircraft manufacturing accounting for 69.8% of the total. The data indicate a positive net impact on US industry, with the value of net input manufacturing activity amounting to USD 13 billion and resulting in the creation or sustainment of 39,925 jobs. Yet, five defence manufacturing sectors register a net loss: aircraft engine and engine parts manufacturing; search, detection, and navigation system and instrument manufacturing; other aircraft parts and auxiliary equipment manufacturing; optical instrument and lens manufacturing; and printed circuit assembly manufacturing, in that order. Aircraft manufacturing, a prime contractor activity, accounts for 94.6% of the total net gain, while the losing sectors are the domain of the subcontracting base, suggesting that offset enables US companies to focus on high-value added production at the expense of a potential loss of domestic supply chain capabilities.

However, interviews with US Company A and US Company B revealed that prime contractors have strong incentives to ensure that domestic suppliers remain operational, not least because the risks associated with relying on foreign companies for the supply of key components are particularly high. In words of US Company B: "We [prime contractor] have to protect ourselves. We cannot afford disruptions to the supply chain due to offset […] we will not shut down the production line if something happens to the foreign supplier and they are unable to deliver […] we need certainty." In pursuit of this certainty, US Company B only uses offset recipient companies as "second-best suppliers," ensuring that US suppliers also receive constant orders even if part of their workloads are relocated overseas in order to meet offset demands. When offset recipients prove to be cost-efficient and competitive in quality and delivery schedules, US Company B continues sourcing components from them after the completion of the offset programme while simultaneously working with its domestic suppliers, thereby generating supply chain diversification, reducing over-reliance on local companies, and increasing its capacity to fill any possible delivery gaps. Importantly also, both US Company A and US Company B expressed the necessity of maintaining robust local supply chains in order to comply with US government regulations when bidding for domestic contracts, as the Buy American Act protects local manufacturers and supply chains by requiring the final product and at least 50% of components to be manufactured in the US (Luckey, 2009). The industrial and commercial imperatives to maintain local supply chains operational has led US Company A to go as far as rescuing small and medium domestic suppliers that were near bankruptcy as a result of workloads being lost to offset.

Both US Company A and US Company B reported that offset obligations are cascaded down to their major subcontractors. These companies are responsible for fulfilling a percentage of the total obligation equivalent to the value of their input contribution to the exported platform. Aware that export sales are crucial for corporate survival, large subcontractors accept their offset share and comply with delivery requirements. However, while the managerial expertise of prime contractors and major subcontractors enable them to undertake due diligence checks on potential offset recipients and select them on a competitive basis,[7] smaller suppliers lack the industrial capability and organisational infrastructure to engage in offset transactions. Therefore, they are left out of the equation for the sake of greater offset effectiveness and efficiency, not least because offset delivery difficulties are often caused by the obligor's lack of familiarity with the extent of industrial capabilities in the recipient economy, resulting in their failing to select suitable recipient companies (Fieldwork, 2012). Ultimately, offset contracts are signed between prime contractors and purchasing governments, and it is therefore contingent upon the former to deliver as agreed and assume responsibility for the offset performance of its subcontractors.

US Company A acknowledged that when it first started formally delivering offset in the late 1970s, offset was perceived as a burden that caused inefficiencies throughout the supply chain by forcing the company to replace trusted, qualified, and certified suppliers with foreign companies of untested and unreliable capabilities that had to be modernised in order to meet production targets and quality standards and obtain the required certifications. However, as the importance of offset in defence procurement contracts increased, the company changed its approach and developed an offset strategy aimed at reconciling its market expansion needs with the technological and industrial development objectives of client countries. Yet, of particular concern was the fact that offset recipients could eventually develop sufficient capabilities that would in turn enable them to undertake the upgrading, support, and maintenance of the exported platform without having to resort to the original equipment manufacturers, thereby eliminating the opportunity for US companies to obtain after-sale contracts. To face this challenge, US Company A ensures that the technological gap is maintained by limiting offset technology transfers to mature technologies whose

[7] This is not always possible, as in most countries there are only a few companies capable of undertaking defence manufacturing. In addition, although most governments allow offset obligors to select recipient companies, some governments are inflexible and appoint recipients unilaterally.

acquisition by foreign companies do not compromise competitive advantages[8] and by making heavy investments in R&D, strategies that are also employed by US Company B.

US Company B deliberately tries to maximise on offset by making use of offset proposals as a key product differentiator in competitive bids and by using strategically planned offset programmes to increase revenue while establishing a permanent presence in key foreign markets through sustainable long-term partnerships. US Company B regards offset as a useful instrument to find competitive suppliers in the importing country, complying with the requirements of purchasing governments while simultaneously generating economic efficiencies as part of a long-term commercial strategy. In the process, the company trains and integrates new suppliers into its global supply chain, thereby improving the likelihood of being awarded future contracts in the importing country due to its possessing well-established local production networks. Indeed, US Company B reported that its offset strategy aims at establishing solid partnerships with recipient industry based on trust and familiarity. To this end, it constantly monitors offset delivery progress, ensuring strict adherence to proven management principles and methods. However, US Company B admits that for the sake of affordability and economic efficiency, offset transactions have to make business sense. Hence, any follow-up contracts granted to former offset recipients have to be won on a competitive basis. In addition, if offset obligations are acquired in other importing countries, workloads might have to be moved to wherever new obligations arise. This is not due to the performance of offset recipients, but to the very nature of offset that gives the demand side the power to shape international production relocation patterns.

In general, unlike the US government, neither US Company A nor US Company B regards offset as an intrinsically negative phenomenon generating adverse effects on the domestic industrial base. Rather, the two prime contractors reported to have obtained commercial and economic gains from offset programmes, with the benefits being in turn trickled-down to their domestic subcontractors. Concomitantly, the two companies have deliberately protected their local supply chains, as relationships of mutual dependence are maintained between the two parties. Thus, although prime contractors' procurement strategies are aligned with offset obligations, efforts are constantly made to maintain domestic suppliers operational. In this context, an emerging trend is that prime contractors are increasingly focusing on using offset to develop strategic industrial relationships with client countries and implementing long-term offset solutions. Offset planning is therefore taking place at earlier stages of the manufacturing process. A case in point is General Dynamics, a leading defence prime contractor that has started "designing for offset" and customising certain products for offset production in purchasing countries (Henriksson and Hermansson, 2011). However, the extent to which this and other offset management strategies are effective not only depends on the prime contractors' performance, but also on that of the offset recipient companies.

5. BARRIERS AND ENABLERS FOR EFFECTIVE OFFSET PERFORMANCE IN RECIPIENT COMPANIES: EVIDENCE FROM SPAIN

From 1984 to 2011, 421 offset agreements were negotiated between the Spanish government and foreign defence contractors, generating a total return of EUR 10.7 billion. Only 36% of all transactions were technology transfers, the remaining 64% having taken the form of order placements with local companies (ISDEFE, 2012). Indeed, work allocation has been the

[8] In addition, all international defence technology transfers, whether they take place through offset or other commercial mechanisms, have to be approved by the US Department of State and the US Department of Defence to eliminate the possibility of transferring cutting-edge technologies and reduce strategic risks.

predominant fulfilling instrument, reflecting the strong interest of the Spanish Ministry of Defence in creating work for local manufacturers. Official accounts of offset performance emphasise the role of offset in generating production activity and causing the enhancement of technological and managerial capabilities. Furthermore, the participation of offset recipient companies as co-producers and suppliers of components and subsystems that have been subsequently integrated into both Spanish and foreign platforms is credited with having increased national exports and consolidated the position of local manufacturers as long-term suppliers of foreign defence prime contractors (Spanish Ministry of Defence, 2000). This in turn has led to the permanent integration of local companies into international supply chains and the acquisition of capabilities and skills that enhance international competitiveness.

In effect, out of the ten surveyed offset recipient companies, only three failed to integrate into the supply chains of foreign defence prime contractors, while the rest continue exporting defence components and subsystems to the US and other major markets to which they got initial access through collaboration with offset obligors. This is a remarkable result, not least because very few countries have experienced the expected offset outcomes (see, e.g. Mitra, 2009). To be sure, the results obtained by Spanish industry vary from company to company, but the largest recipient companies report that offset agreements enabled them to enhance technological and industrial capabilities, with the gains being in turn trickled-down to the domestic supply base. Smaller companies, however, were largely unable to share the benefits with third-tier suppliers, as the latter lacked the required certifications to participate in US-led manufacturing and therefore recipient companies at the second-tier level often had to source raw materials and parts from US-based companies, demonstrating that some offset work returned to US suppliers due to the lack of sufficient capability in the recipient industry.

Recipient companies acknowledged that although offset does generate substantial production activity, not all of it is high value-added. In effect, none of the ten surveyed companies reported to have received R&D as offset, a fact that is consistent with the prime contractors' strategy of maintaining knowledge-intensive and high value-added production activities in their home countries. Notwithstanding, the ten companies stated that participation in offset production had served as a catalyst for extra corporate investments in R&D that would unlikely have occurred had the offset programmes not taken place. In addition, seven companies reported to have transferred offset-derived knowledge, skills, and technologies to their subcontracting base. The most cited benefits enabling offset recipients to permanently integrate into international defence supply chains were product and process technology transfers, harmonisation of management and manufacturing practices with those of foreign prime contractors, quality control enhancement, and international visibility. Second-tier suppliers recognised that without the offset obligation their capabilities as defence suppliers would likely have remained unknown to foreign primes, with one company stating that "we [second-tier supplier] are very small and would never have been approached by [US Company B] if there had not been an offset obligation they had to fulfil."

Permanent integration into international defence supply chains was not easy to achieve and companies that did become permanent suppliers of foreign prime contractors made systematic and strategic use of offset to enhance capabilities, develop competitive advantages in niche sectors, and position themselves in international markets, regarding "offset [as] a business development mechanism, not a temporary gain." In contrast, companies that failed to achieve similar results had a focus on obtaining sufficient workloads to maintain production plants open and lacked a clear strategy for long-term sustainability. In addition, the strategy of top performers included substantial financial investments in the acquisition of general manufacturing capabilities, the development of production processes, and productivity and efficiency enhancement to achieve levels comparable to those of US suppliers. Moreover, successful companies reported that large investments in R&D were fundamental, not least because, unless export licenses are granted by offset suppliers, the development of original products is necessary in order to access and maintain a presence in foreign markets once the offset obligation has been fully discharged.

In this respect, both offset suppliers and recipients recognised that the modernisation and enhancement of capabilities achieved through offset, when supported with further corporate investments, were sufficient to compete internationally. Yet, a fundamental pre-requisite for effective offset performance was the possession of enough technological and industrial assets to successfully absorb offset in any form. Hence, companies that initially lacked such assets made the necessary investments to acquire them prior to the commencement of the offset programme. Once the infrastructure was in place, the focus shifted to securing the transfer of key technologies needed to fill capability gaps and achieve production targets. Needless to say, the collaboration and guidance of offset suppliers throughout the process was crucial, not least because in some instances it was the case that the quality of Spanish-made components was acceptable until several batches had been produced, requiring the offset fulfiller to send quality engineers to directly control, supervise, and audit manufacturing processes. Thus, the collaboration, flexibility, and commitment of offset suppliers are credited with having accelerated the process of technology absorption and adaptation.

A major challenge that offset recipients faced was the initial lack of familiarity with advanced manufacturing and management systems employed by offset fulfillers, resulting in multiple organisational and technical adaptations being required in order to meet product specifications, quality standards, and delivery deadlines. Small companies also reported that a big difficulty was the increase in scale, as they were used to short production runs and had no experience handling large orders for international markets. Furthermore, although local supply networks existed, it was also necessary for offset recipients to establish new supply chains that included foreign companies, leading to insufficient indigenisation of the production process. Yet, first and second-tier recipient companies were indifferent to whether their suppliers were local or foreign, having no objection to grant contracts to companies in the offset supplier's country of origin in order to save time and money in accreditation processes. In fact, selecting suppliers that were already certified and possessed proved capabilities was perceived as an added advantage that also helped offset recipients create and expand business networks in foreign markets. This makes commercial sense and improves competitiveness, but has an adverse effect on local suppliers that do not get to directly benefit from the offset programme. Moreover, offshore outsourcing the production of parts needed to complete offset work ends up reducing the capacity of local industry to achieve higher levels of self-sufficiency, the principal objective of the Spanish offset policy.

6. CONCLUSIONS

The defence industry produces complex, high-tech, high value-added products of strategic and national security importance in an imperfect market dominated by government intervention. In this context, offset has become a critical force shaping the structure of the international defence manufacturing system by generating a situation of interdependence between the industries of the importing and exporting countries and causing the reconfiguration of international supply chains. Indeed, unlike civil markets where companies tend to structure supply chains based on cost, quality, and efficiency considerations, defence manufacturers have to agree to the constant international reconfiguration of supply chains upon explicit demands from client governments eager to share the economic, technological, and industrial benefits of defence production. Under these conditions, defence companies that are able to develop the most offset-adaptable and flexible supply chains, accounting for unique market and product characteristics and complexities, enhance their market position and generate additional competitive advantages. It is therefore of paramount importance to understand the dynamics involved and empirically evaluate the effects of offset on both supplying and recipient companies in order to design suitable offset management strategies that deliver effective outcomes taking into consideration the interests of all stakeholders.

This study has presented empirical evidence demonstrating that two of the world's leading defence companies have turned a market-distorting mechanism influenced by political variables into a business tool actively employed to strengthen international competitiveness. The experience of these companies suggests that contrary to the US government's official and dogmatic position, in the long-run offset is not necessarily welfare-diminishing. While it is true that defence exporting companies would not engage in offset if importing governments did not require it as a condition of purchase, evidence shows that offset fulfillers do obtain commercial gains as a result of their participation in offset programmes. These benefits include the effective use of offset as a product differentiator in competitive bids, identification of new cost-efficient suppliers in offset recipient countries, supply chain diversification, establishment of solid partnerships and permanent business networks in large defence markets, and ability to have domestic manufacturers focus on higher value-added activities. Furthermore, US prime contractors manage offset in a careful and strategic manner in order to protect national supply chains and ensure that the fulfilment of offset obligations does not lead to a loss of national defence production capacity.

On the demand side, evidence gathered from Spanish offset recipients demonstrates that offset can indeed be effectively employed by manufacturers in the importing country to develop capabilities and integrate into international defence supply chains. Effective offset absorption requires less technologically and industrially advanced recipients to go through long and arduous learning processes. This, however, is not enough. Integration into international supply chains also requires a series of conditions to be in place prior, during, and after participation in offset programmes. Above all, serious commitment to long-term strategies and investments is necessary. Without this, sustainability is unachievable. Offset is merely a door-opener whose benefits to companies in the importing country end when the obligation is fully discharged unless recipients make strategic use of offset to enhance critical capabilities and put in place robust long-term development strategies to compete internationally on their own merits in the post-offset phase.

In the end, economic rationality prevails and even though offset does influence the structure and configuration of the international defence manufacturing system, reliance on offset to maintain a position in international supply chains is unviable. Hence, offset should be regarded by recipients as an opportunity to obtain initial access to a market with very high entry barriers, while recognising that in order to succeed and remain integrated into international defence supply chains, sound strategies, effective performance, and substantial investments are essential. When offset is employed in this manner and suppliers also adopt a strategic and collaborative approach to offset management, long-term offset outcomes are bound to benefit both parties and the international defence manufacturing system as a whole.

REFERENCES

Avascent, 2012, “The Half-Trillion Dollar Challenge: Designing Offset Strategies to Build Reputation, Promote Development,” http://www.strategicoffsets.com, downloaded 20 April 2013.

Balakrishnan, K. and R. Matthews, 2008, “Defence Industrialisation through Offsets: A Case Study of Malaysia,” *Defence and Peace Economics*, Vol. 20, No. 4.

Brauer, J. and Dunne, P., 2004, *Arms Trade and Economic Development: Theory, Policy and Cases in Arms Trade Offsets*, New York: Routledge.

CTO Data Services Co., 2012, *The Offset Guidelines Quarterly Bulletin*, July.

Epicos, 2012, “Offsets Introduction,” http://www.epicos.com, accessed 28 July 2012.

Frost & Sullivan, 2013, “Military Offsets & In-country Industrialisation: Market Insight,” downloaded 27 July 2013.

Henriksson, K. and M. Hermansson, 2011, “Offset Management: A Case Study of Saab AB,” Master of Science Thesis, Department of Technology Management and Economics, Gothenburg: Chalmers University of Technology.

ISDEFE, 2012, Internal Document, Fieldwork, Madrid, September 2012.

Luckey, J., 2009, “The Buy American Act: Requiring Government Procurement to Come from Domestic Sources,” Washington: Congressional Research Service.

Martin, S. (ed.), 1996, *The Economics of Offsets: Defense Procurement and Countertrade*, Amsterdam: Harwood.

Martin, S. and K. Hartley, 1995, “UK Firms’ Experience and Perceptions of Defence Offsets: Survey Results,” *Defence and Peace Economics*, Vol. 6.

Matthews, R., 1996, “Saudi Arabia’s Defence Offset Programmes: Progress, Policy and Performance,” *Defence and Peace Economics*, Vol. 7.

Matthews, R. and J. Parker, 1999, “Prime Contracting in Major Defense Contracts,” *Defense Analysis*, Vol. 15, No. 1.

Mitra, A., 2009, “A Survey of Successful Offset Experiences Worldwide,” *Journal of Defence Studies*, Vol. 3, No. 1.

Murman, E. et al., 2002, *Lean Enterprise Value: Insights from MIT´s Lean Aerospace Initiative*, New York: Palgrave.

Neuman, S., 1985, “Coproduction, Barter, and Countertrade: Offsets in the International Arms Market,” *ORBIS*, Vol., 29, No. 1.

Reuters, 2012, "Defense Supply Chains Threatened by Spending Cuts," *The Fiscal Times*, http://www.thefiscaltimes.com/Articles/2012/09/10/, accessed 10 August 2013.

SIPRI, 2011, "The SIPRI Top 100 Arms Producing and Military Services Companies, 2010," http://www.sipri.org, accessed 20 July 2012.

SIPRI, 2012, "Military Expenditure by Region in Constant US Dollars," SIPRI Military Expenditure Database, http://www.sipri.org, accessed 25 July 2012.

Sköns, E. and H. Wulf, "The Internationalization of the Arms Industry," *Annals of the American Science of Political and Social Science*, Vol. 535.

Spanish Ministry of Defence, 2000, *15 Años de Cooperación Industrial en el Sector de la Defensa*, Madrid: Ministerio de Defensa.

Udis, B. and K. Maskus, 1991, "Offsets as Industrial Policy: Lessons from Aerospace," *Defence Economics*, Vol. 2.

US Government, 1990, "Presidential Policy on Offsets in Military Exports," http://www.disam.dsca.mil/pubs/Indexes/Vol%2012-4/Offsets.pdf, accessed 10 August 2012.

US Department of Commerce, 2013, "Offsets in Defense Trade: Seventeenth Study," Washington: Bureau of Industry and Security.

Uttley, M., 2001, "Defense Offsets, Weapons Proliferation and Emerging Security Challenges," *Defense Studies*, Vol. 1, No. 1.

Wessner, C. W. (ed.), 1998, *Trends and Challenges in Aerospace Offsets*, Washington: National Academy Press.

A High Value Production Network - At Work

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Abstract

The paper seeks to contribute to an understanding of how inter-firm relationships, both material and social, are critical elements of an effective cluster network where unlike traditional mass manufacturing clusters, the requirement for novel high value bespoke products requires an engineer-to-order model integrating latest advances in component and equipment technology and the integration of prototype design-build-supply-service models.

The study focusses on the dynamic capabilities and the network relationships of a leading actor within the Norwegian maritime cluster, who represents approximately 40% of the total turnover of Norwegian shipyards. The research examines the interactions with vendors in particular, and the proactive role taken to manage the supply chain and increase the value-add of network partners. The maritime cluster used in this analysis is located off the west coast of Norway, representing a significant and profitable high value manufacturing network. Usually referred to as the Møre and Romsdal maritime cluster, the cluster is regarded as the leading innovative industrial district and production network within the offshore service sector in Norway, with a dominant global position in the supply of high-value offshore maritime vessels.

Key words: High Value Production, Network, Maritime Industry, Cluster

Introduction

The Industrial Context
Before the shipbuilding industry is elaborated, some market and development characteristics as background data for the regional shipbuilding industry will be presented.
The global petroleum industry has a complex structure and comprises elements of exploration, development, production, refining, transporting and marketing petroleum products worldwide. The overview provides information about recent market developments related to exploration,

development and production elements of the industry, more specifically, upstream activities which deploy *Offshore Specialized Vessels* (hereafter OSV). The global fleet of OSVs consists of several types of vessels – examples are:
a) PSV– Platform Supply Vessels; b) AHTS – Anchor Handling Tug Supply Vessels; c) Seismic Exploration Vessels; d) Well Intervention Vessels, and e) Construction Vessels.
Oil and gas companies are the main actors that participate in activities related to exploration, development and production of natural resources offshore. Other actors are seismic exploration, drilling and subsea entrepreneurs. Suppliers can be divided into those that supply goods and services, and those who design and build OSVs and are engaged in after-sales services including spare parts and preventive maintenance for their products.
Another group of actors in this market are ship owner companies (also called ship operators).
Most of them see offshore supply and anchor handling services as their primary business activities. The global market has gained a significant OSV capacity (tonnage) during a 6-year period from 2006 to 2012[1].
The largest Norwegian OSV owner company, Farstad Shipping ASA, is a global actor and is present at several geographic locations worldwide.

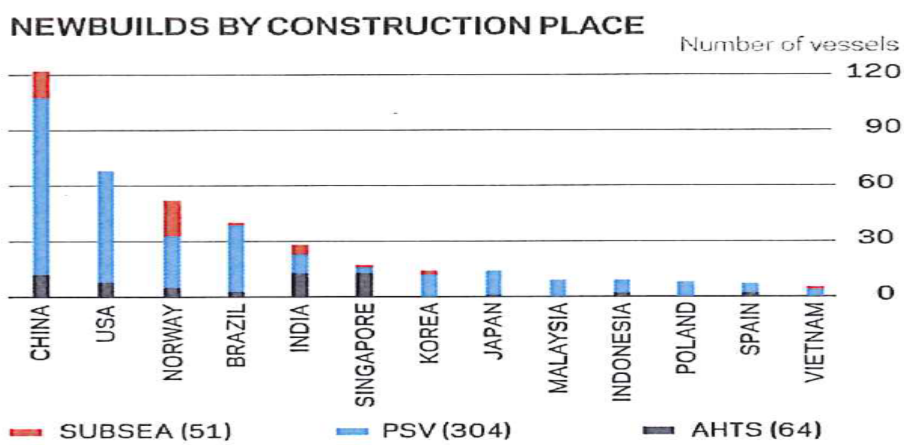


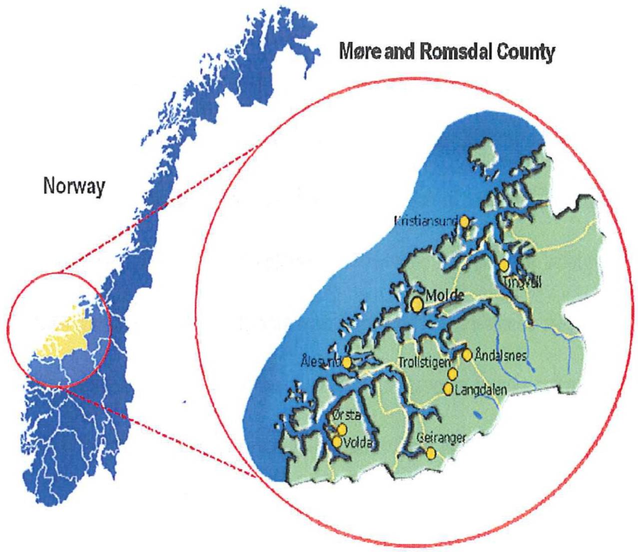
Figure 1. New-built vessels worldwide, sorted bas per December 2012[2]

China is by far the largest builder of vessels. They build nearly twice as much as USA and nearly three times as much as Norway. More important though is the fact that the Norway shipbuilding industry build more advanced vessels and to a significant higher value. China is big on low- end market product and especially at the carriers of the sea, the PSVs.
In the annual report, 2012, Farstad ASA states that *"the maritime industry in Norway still has a central position in the development of new offshore vessels, and Norwegian shipyards still have a leading position in the construction of the more advanced offshore vessels"*. (Farstad ASA (2012)

The maritime industry in Møre and Romsdal, Norway

The Møre & Romsdal Maritime Cluster (hereafter M&R Maritime Cluster) is a part of the Norwegian maritime industry where emphasis is almost solely on designing and building OSVs. Møre & Romsdal is a county in the northernmost part of Western Norway.

[1] Vessels contracted earlier, planned deliveries in 2011/2012
[2] https://www.farstad.com/en/annualreport2012/downloads



The M&R Maritime Cluster consists of[1]:
- 15 ship design and engineering companies
- 14 shipyards
- 165 equipment suppliers and construction service providers
- 19 Offshore service shipping companies / ship owners

Figure 2. The Geography of the M&R Maritime Cluster

The debate about outsourcing has been running for years, but the debate became more audible and open after the research projects resulted in 'The competitive advantage of nations' (Porter, 1990). In the years to come, many countries, including Norway, carried out national research projects to investigate their national competitive advantages and subsequently tried to define industries that were competitive (Reve *et al.*, 1992). The Norwegian project concluded that the shipbuilding industry, which is Norway's oldest competence based industry, probably was the *best example of a highly competitive knowledge-based industrial cluster.*
M&R is the largest industrial maritime region in Norway (when petro/offshore is excluded) (Hervik and Jakobsen, 2001). In 2009 the total turnover came close to 50 billion NOK (figure 3).

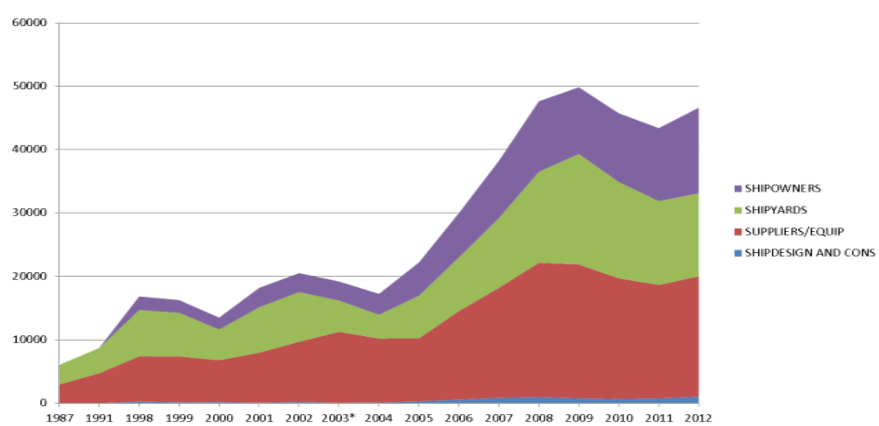


Figure 3. Cluster turnover (1987-2012). (MFM, 2012)

The maritime cluster in M&R has evolved over a long period of time, from fishing vessels, through fjord ferries, to equipping, fitting and exporting technologically advanced vessels, which need to operate in the severest maritime environments. Whilst some firms have disappeared along the way and important new firms have been founded, a significant number of companies within the region have transformed themselves in response to external changes. The corporate continuity, with many family- owned enterprises was until quite recently complemented by a high degree of stability in ownership and management. Therefore, when taken together with a reasonable spatial concentration of firms, this sector has many of the attributes favouring a well-functioning cluster – using the word both as a noun (an agglomeration with a distinctive local labour market and with a respected image in the market) and a verb (with the connotation of productive networking relationships).

During the 1980s and 90s much of the disaggregation or disintegration of the shipyards took place and activities outsourced. These facts partly laid the foundation for a competitive supplier industry in the region. The disaggregation of the previously integrated shipyards has strengthened the competitive position of the supplier group as a whole and the companies within the group. We have seen that the largest maritime industrial cluster in Norway has been successful according to different by metrics. The growth in value creation (turnover[3]) has been significant (fig.3) and all sectors in the industry have been profitable (fig.4) even though there are great variations both between the different sectors in the value chain and between companies within the different sectors (figure 3-5).

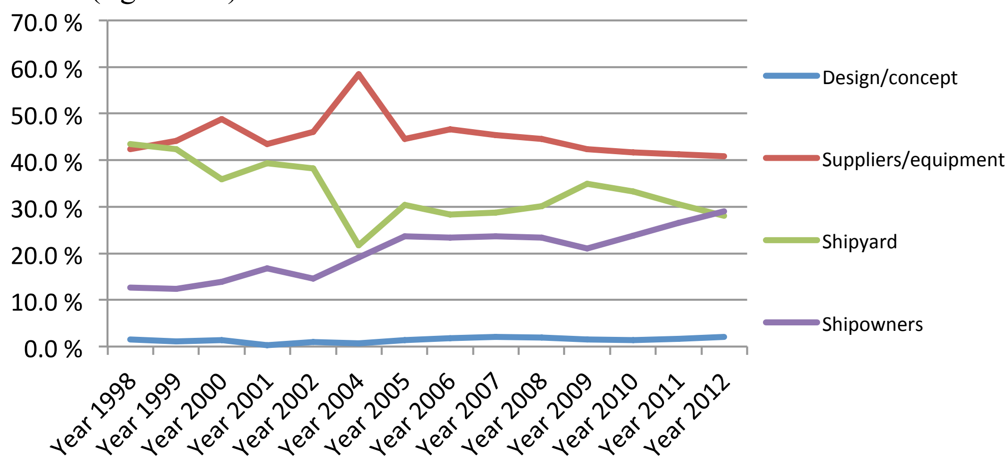


Figure 4. Proportion of total turnover in the value producing network. (MFM, 2012)

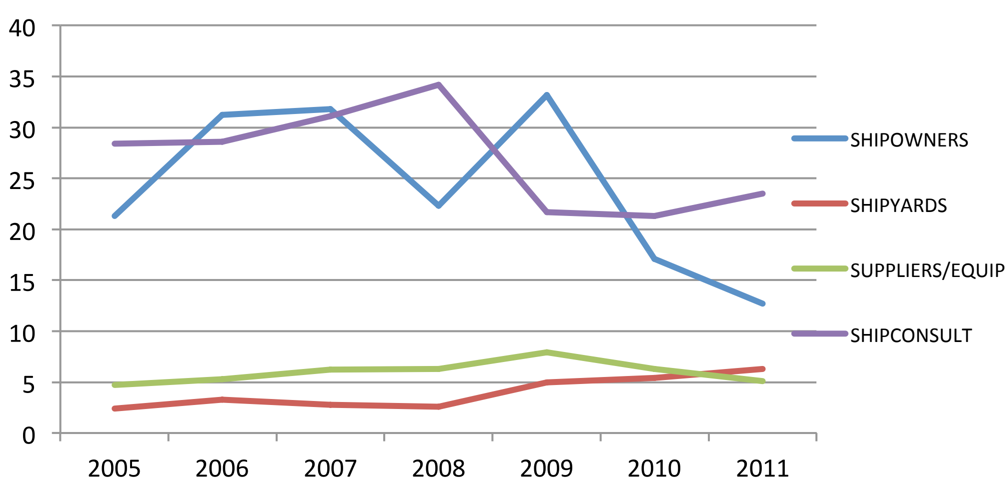


Figure 5. Operating profit margin (%) (MFM, 2012)

3 So far we have used turnover as a unit of measure or illustration of value creation or value added.

The evolution of the district and companies is not only positive nor linear, which also may be seen from the figures above. The turnover today is close to five times higher than 15 years ago. There are many more suppliers today and the suppliers are more independent of the local shipyards due to increased export. The cluster with its main suppliers has become global.
The products produced are of high value, actually of the highest value. The products are unique in the way that there is only one copy of the product, it is one-of the kind product on customers request or engineered to order (ETO). The products are characterised by being complex and highly innovative. The emergence and the growth of a maritime cluster on the north- west coast of Norway has been shown.
The paper seeks to understand to what extent inter-firm relationships are critical elements of this kind of high value manufacturing network and how they function

The value creating network complexity
Within different theoretic perspectives like Supply Chain Management, Operations Management, and Systems Theory, substantial research regarding value creation network evolution, complexity, dynamics, methods of analysis, strategy and configuration has been made. Furthermore, these theories and their approach towards understanding value creation networks as complex systems differ with respect to core assumptions, predictions and the unit and level of analysis.
First the concept of *value creation network* could be defined in the context of manufacturing. According to Möller et al. (2002) and Rudberg and West (2008), it is important to distinguish between a "*network of organizations*" and a "*network organization*". The former refers to any *group of organizations* that are interconnected with exchange relationships. The latter refers to a *single organization that consists of independent business units or facilities*.
Furthermore, Rudberg and Olhager (2003) classify networks in terms of the number of organizations in the networks and the number of sites per organization. They differ between supply chains (multi-organization, single-site focus) and intra-firm networks (single-organizations, multi-site focus). Hence, a value creation network is regarded as a network of facilities, possibly owned by different organizations, where time, place or shape utility is added to a good in various stages such that the value for the ultimate customer is increased.

Research on manufacturing networks has its roots in the manufacturing management of the single factory (Rudberg and Olhager, 2003). In the 1950s and 1960s, most manufacturers emphasized mass production to minimize unit production cost as the primary operations strategy, with little product or process flexibility. New product development was slow and relied exclusively on in-house technology and capacity. Bottleneck operations were cushioned with inventory to maintain a balanced line flow, resulting in huge investment in work in process (WIP) inventory. Sharing technology and expertise with customers or suppliers was considered too risky and unacceptable and little emphasis was placed on cooperative and strategic buyer – supplier partnership (Tan, 2001).
During the late 1980s and 1990s it was impossible for manufacturing to withstand the trend of globalization, and companies established more and more factories on a wider international basis. Research on operations management was extended from multi-plant to network issues. In parallel, the terms Supply Chain Management (SCM) and Michael Porter's Value Chain were originally introduced in order to describe strategic, inter-organizational issues, to discuss an alternative organizational form to vertical integration, to identify and describe the relationship a

company develops with its suppliers and customers, and to address the purchasing and supply perspective (Chen and Paulraj, 2004; Rudberg and Olhager, 2003 & Shi and Gregory, 1998).

The role of manufacturing companies has changed from supplying domestic markets with products, via supplying international markets through export, to supply international markets through local manufacturing. Hence, the research on international issues in manufacturing has evolved from global sales and marketing into global manufacturing (Rudberg and Olhager, 2003). As a result of the abovementioned changes and new challenges, studies of supply and manufacturing networks from a complex system perspective began to accelerate in late 1990s and early 2000.

Porter (2000) defined 'clusters' as geographic concentrations of interconnected companies, specialized suppliers and service providers, firms in interrelated industries, and associated institutions (e.g. universities, standard agencies and trade associations) in particular fields that compete but also cooperate. The main advantages of the concept as we see it, is the systemic nature of the concept enabling the study of interactions and interdependencies on different levels of aggregation/detailing level. The concept is far from clear cut and one of the main discussions is related to whether clusters and clustering are primarily functional or indeed spatial phenomena (Malmberg and Power, 2003). The cluster concept as defined by Porter (2000) is badly related to knowledge creation and shared and how the knowledge sharing affects innovation.

When studying globalization, many theories have focused on the changes, relationships and dynamics of the three dimensions; geography, activities and configuration (Sakuda and Fleury, 2012).

A linear, traditional "chain" perspective was useful for planning certain mechanical aspects of transactions between buyers and suppliers – however, it failed and still fails to capture the complexity needed to understand a firm's strategy or behavior, as both depend on a larger supply network that the firm is embedded in. (Choi et al., 2001; Pathak et al., 2007). Impact of continuously changing market landscape and interconnections between multiple suppliers, manufacturers, assemblers, distributors, and retailers became increasingly significant in industrial supply/manufacturing networks. Lack of prediction and control challenged both managers and researchers (Choi et al., 2001; Pathak et al., 2007).

The literature increasingly devotes attention to the study of business networks. However, there remains a broad range of definitions regarding what constitutes a complex system. A vast amount of research has been carried out regarding studying, predicting, and controlling ''chaotic'', non-linear systems in biology, physical sciences, engineering and similar. The knowledge has gradually been incorporated in the organizational theory literature where the stream also has extended to the supply chain management literature (Bozarth et al., 2009).

Normann and Ramirez (1993) supplanted the traditional concept of the linear supply/value chain by the new notion of value networks, or 'constellations'. The authors generalized that successful companies should conceive strategy as systematic innovation: the continuous design and redesign of complex business systems; Wilding (1998) studied dynamic events in supply networks through what he referred to as "supply chain complexity triangle"; Shi and Gregory (1998) viewed manufacturing networks as a factory networks with matrix connections, where each node (i.e. factory) affects the other nodes and hence cannot be managed in isolation; Choi et al. (2001) conceptualized supply networks as complex adaptive systems (CAS); and, Pathak et al. (2007) discussed the usefulness of CAS principles in identifying complex phenomena in supply networks. Among other concept in use that tries to conceptualize the value creation processes and the network structure, strategic business nets (Møller et al., 2005) and business networks (Håkanson and Snehota, 2006) could be mentioned.

Today most people working in this field agree that a supply or a manufacturing network is a complicated system where value is co-created by combinations, constellations or configurations of actors in the network (Bozarth et al., 2009; Peppard and Rylander, 2006; Srai and Gregory, 2008). Besides, there are also some general agreement upon the fact that one of the major challenges for corporate strategists is to develop a network structure and value co-creation mechanism that can facilitate adaptive, flexible and synchronized behaviors in a dynamic, global environment (Pathak et al., 2007; Srai and Gregory, 2008). Every scholar in the field is advocating a better understanding of how value is created in business networks or systems, rather than merely in business relationships or at the level of single actors (Corsaro et al., 2012).

As we have pointed out earlier, research is still in the early stages of investigating the general principles that govern the birth, growth and evolution of supply and manufacturing networks with complex network structure and mechanisms for collaboration and value co-creation (Corsaro et al.,2012). Today, multiple and complex relations and connections between actors upstream and downstream are the normal picture for value creation production networks.

The view of value co-creation emphasizes the focus on company core capabilities and competence complementarities. The fact that different actors have developed different capabilities and cooperate (and compete) with other value creators are what constitute the network. The process of value creation is not simple, linear or sequential. The process is complex involving multiple actors in process oriented and 'chaotic-like' processes. Actors' contribution to solutions focuses on their core competences and on the cooperation of other network actors, such as suppliers, partners, allies, and customers (Basole & Rouse, 2008, Ford *et al.*, 1998, Matthyssens et al.,2009).

High value manufacturing always involves both products and different kind of services, after services and solutions. The combination of innovative ETO, products and different kinds of services, system solutions as opposed to product solutions require the coordination of value creating processes in the many different company systems like ERP (supply, stock, order and production) systems, maintenance systems, spare parts supply systems, logistic systems, and so on (Cohen *et al.*, 2006; Davies *et al.*, 2007). It is almost impossible to work with other companies on arm's length distance. Strong relationships between the different firms, the firm's position in the network, and the firm's network horizon arguably enhance the provision of solutions (Windahl & Lakemond, 2006).

The resource-based view examines how different kinds of capabilities (certain kind of resources and the way they are used) influence the positioning or the competitive advantage of the firm. In Barney (1991) there is support for the view that special capabilities are attached to companies with the best value supply chains, meaning that network capabilities exist at the supply chain level. Dynamic capabilities are both internal and external (cross organisational). The internal capabilities lay the foundation for superior performance, but the best organisations also possess capabilities that cross organisational borders and involve multiple organisations in working together to create or maintain competitive advantage (Defee and Fugate, 2010). The study of external capabilities has been scarce. The application of dynamic capabilities to the real world context of interdependent inter-firm network has not been explored (Alinaghian et al., 2012)

The co-creation of value as discussed call for focal companies to act strategically different on their suppliers. Few could or should be kept on arm's length distance. No organisation can create value in isolation. This meaning that both supplier development and strategic partnering is becoming increasingly important and that management and development of capabilities in supply networks are included in core business processes.

This paper investigates into the extent of close relations in the high value maritime manufacturing network of M&R in Norway.
In a case study, external dynamic capabilities are explored by studying a significant actor in the industry and how the focal company involves multiple organisations in working together to create competitive advantage.

3. Methodology

The study seeks to answer a) the extent and importance of inter-firm-relationships in high value manufacturing network and b) how a significant actor works or uses dynamic capabilities of the companies to strategically position the high value manufacturing network.
The first unit of analysis defined in the study is the maritime industry/ network in the county of Møre and Romsdal on the west coast of Norway. On this level, the unit of analysis holds all the important actors to the industry system or network as ship owners, ship-yards, suppliers and consultants/designers.
In the exploratory case study, the largest ship building group in Norway, STX OSV[4] is chosen to explore the company's relationships within the network. The company operates five yards in Norway in addition to shipbuilding activities in Romania, Vietnam and Brazil. The company constitute approximately 40% of the total turnover of Norwegian shipyards
First the data from a yearly performed survey on the maritime industry in the Møre and Romsdal county was explored. The study, which collects data from the maritime industry, goes back to the beginning of the1990's and constitute the foundation of the analysis of the Møre and Romsdal maritime cluster.

	Number of firms in the population	Response rate proportion firms	Response rate proportion of turnover
Suppliers of equipment and services	165	33%	74%
Shipowners	19	63%	87%
Shipping consultants/design	15	67%	92%
Shipyards	14	86%	99%
Sum	213	42%	85%

Table 1. Population and respondents in the survey of maritime companies in Møre and Romsdal, 2012

The number of companies in the survey represents 42% of all companies and 85% of the total turnover in the cluster.
The selection of the prime manufacturer as a proxy for a supply network is supported by Humphrey and Schmitz (2001). Prime manufacturers can provide key insights on supply networks on both upstream and downstream aspects in the maritime industry.
Both qualitative and quantitative research methods have been used at STX ASA to build the primary database used in the supplier analysis. In-depth interviews in the form of focus group/expert group were carried out with strategic and operational level at STX ASA involved.

[4] This summer STX OSV was sold to the Italian Fincantieri and is named VARD AS

The second data set consist of the STX OSV's supplier/buying data base combined with qualified assessment and classification of the data, performed by an expert/focus group of four key personnel from STX OSV. All the supply and all the suppliers were grouped and analysed.

Following the collection of the historical purchase data, these data, were organized both by supplier and by SFI[5] product system, to have a better basis for further analysis. During the process of organizing the data the focus group met regularly to secure that the data was correctly re-organized. Further discussions took place within the project team where the researchers were involved.
These key personnel occupied roles in the company that made them knowledgeable about the issues regarding the research. Research done by John and Reve (1982) show that significant correlation exists between information gathered from key informants from both sides in buyer-supplier relationships. "…results indicate that key informants from different firms within channel dyads provided reliable and valid data about the structural form of the relationship investigated…" (John and Reve, 1982, p. 522).

4.0 Analysis and findings

4.1 The maritime cluster network

In the study we have defined the network along two dimensions the economic transactions and the espoused importance of relations. The two dimensions can be compared with Argyris and Schon (1974) concepts of theories in use and theories as espoused which are. We don't always do what we are saying we are doing. The first dimension is the espoused relations between the actors when with whom they engage in relations with and the importance of the specific relationship. The result for the year 2009 is depicted in figure 6.

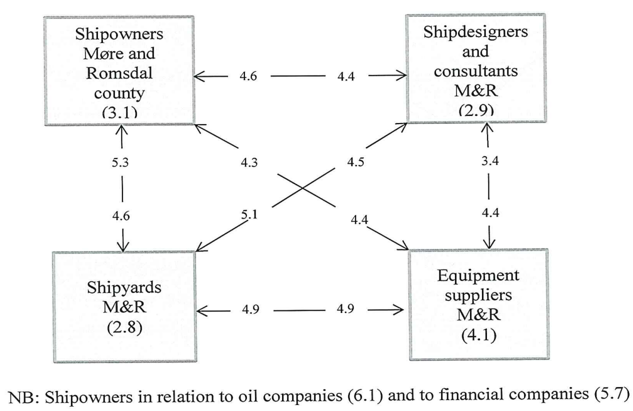


Figure 6. Relations between actor in the maritime industry in M&R, average score (the scale from 1-7 where 1 i= 'no relation' and 7 is 'strong relation')

The survey with this question has been conducted in the years 2001, 2003 and 2006 in addition to this (2009) and the relationships have both been stronger and weaker due to different elements like market situations, financial crises, etc. Irrespective of this, the figures show strong and mutual relationships between all actors. It is said that the innovative capacity and capability is related to the close relationships between the shipyards and the suppliers and the customers, the

[5] SFI is a common code for the flow of information between enterprises within the maritime and offshore industry. In STX OSV, each product group has a designated SFI-code. This SFI-code is used throughout the system with regards to purchase, installation, booking, etc. SFI codes have been used to secure easy implementation and understanding of the derived results

customer relation being the most important (Halse & Bjarnar, 2011) An important proof of how well the network or the cluster functions is to map the co-creation of value between the actors. One clear sign of co-creation of value is the extent of financial streams between the actors of the supposed network. The financial streams between the actors not only symbolize the relations between the firms, but are actually proof of economic transactions between them.

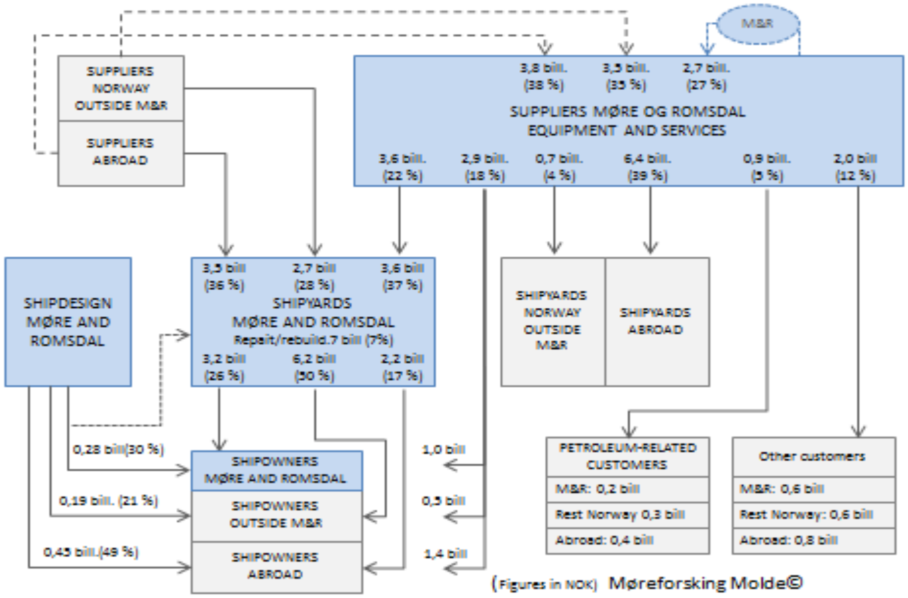


Figure 7. The economic interplay between the actors in the maritime industry in M&R, 2011

As can be seen from the figure above, the economic transactions between the actors are significant. The sales and percentages vary from one year to another due to fluctuations in production and demand, but is on average quite stable. Yards in the county purchased goods and services from local suppliers, representing 37 % of the yards ' total purchases and 22 % of the suppliers' turnover. In 2010, the shipyards' purchases from local suppliers representing 46 % of total purchases and that correspond to 28% of the local contractor's total sales that year. Previous analyzes of the industry showed that the yards in the county had a purchase share in excess of 40 % from local suppliers in 2008-2009. From the suppliers' side the supplying to local shipyards constituted respectively 27% and 24 % in 2008 and 2009. The supplier firms in M&R, included in this analysis, have a high share of deliveries to the shipbuilding industry. Overall, the suppliers in the county had an export share of 55 % of their goods and services in 2011 and a significant proportion of this was directed at foreign shipyards. Overall, 65 % of the purchases to the shipyards in the county were sourced from Norwegian suppliers in 2011. An analysis of the effects associated with STX OSV's shipyard operations in Norway (Oterhals et al, 2011) showed that 66 % of total purchases came from the Norwegian suppliers and as much as 42 % came from suppliers in their own county.
The economic transactions show how the companies are related and also show the changes in economic relations over time. *But the patterns give no answers to the question why they are related*. Companies specialize both horizontally in products and/or vertically in phases of production along the chain of value adding activities. The division of labour between specialized firms may be seen as a source of external economies of both scope and scale (i.e., economies

external to the firm but internal to the cluster or system of firm), raising their collective innovative potential (Bellandi, 1989). Even though specialization is a company specific competence, each firm contributes to the cluster's innovative capacity. By altering the nature and pattern of interdependency, specialization has implication for interfirm relations (Staber and Morrison, 1999). Knowledge creation and innovation capability are important parts of the dynamic capability construct both on the firm and on the cluster level.

Firms are exploring new business models and building strategies which develop and align internal and inter-organisational dynamic capabilities to external possibilities and threats. The next part will examine how a leading actor in this high value manufacturing industry develop knowledge around key strategic challenges for the industry and how they act strategically to manage value creation and value capture in an increasingly global production network by involving multiple organisations in a network. The companies' dynamic capabilities are used to strategically position the network within the global value chain.

4.2 The strategic part of value co-creation

STX OSV is a key player in the Norwegian shipbuilding industry, constituting approximately 40 percent of total turnover from Norwegian shipyards. In 2011, MFM and STX OSV conducted a study that showed that as much as 66 percent of total purchasing costs were derived from Norwegian suppliers, and a close cooperation exists between shipbuilding activities and suppliers (Oterhals, Johannessen & Hervik, 2011).

The MFM database contains more than 200 maritime-related companies. In 2010, 162 of these companies were classified as suppliers, and the remainder were classified as shipowners, design companies and shipyards. The supplier group is by far the most comprehensive and diversified. If 15 design companies are added to the supplier group, then this study analyses a total of 177 suppliers. Rarely the companies are totally engaged to one activity or classification only. Therefore, the activities between the groups are distributed by percentage to obtain a kind of relative weighting for each category. Every supplier was assessed by the project group.

Supplier category	**Representations**[6]	**Relative no**[7]
Design and engineering	49	34
Steelwork – hull	1	0.5
Ship equipment supplier	141	116
Construction service provider	35	21
Capital equipment	8	5

Table 2. Number of companies within each supplier category

For the purpose of this study, companies including ship equipment supply were found to be most relevant and interesting and are also, by far the group with highest potential. The remainder of the analysis will therefore be concentrated on a further classification of the equipment suppliers. The classification is based on product complexity (PC) and competence intensity (CI).

Each equipment supplier in the database was assigned a low, medium or high score, ranging from 1 to 3, to reflect each of the two attributes, PC and CI. Figure 8 displays this classification and

[6] Total number of companies related to this category

[7] Relative number of companies within this category

denomination. Combining these two attributes as the mean of PC+CI results in a classification illustrated as A, B, C, D and E in figure 8.
Assigning this combined score for (PC,CI) results in a distribution, as illustrated in figure 9.The figure depicts the relative number of companies and also the total number of occurrences in each square.

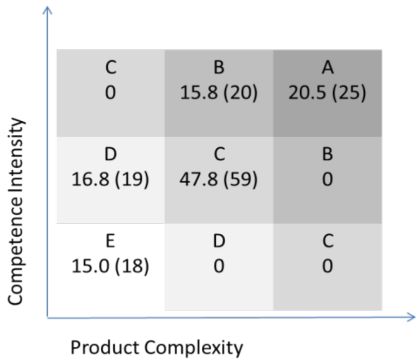


Figure 8. Classification and denomination of equipment suppliers (n=141)

As could be expected there are no product with high product complexity and low firm competence intensity (lower right corner) and nor is it any company on the upper left corner with low product complexity and high firm knowledge intensity(C). 20.5% of the companies are classified as high competence/high product complexity firms (A). The classification is now used to analyse the profitability between high and low competence/product complexity firms.

4.3 The value capturing firms

This chapter analyses empirical financial data from regional shipbuilding suppliers based on the classification of suppliers above and empirical financial data on regional maritime suppliers.

Figure 9 displays the pre-tax profit margin for equipment suppliers during 2000–2010. The average curve describing pre-tax profit margins for all equipment suppliers fluctuated between 4- and 6 percent during 2000–2005 and between 5- and 10 percent during 2005–2010.

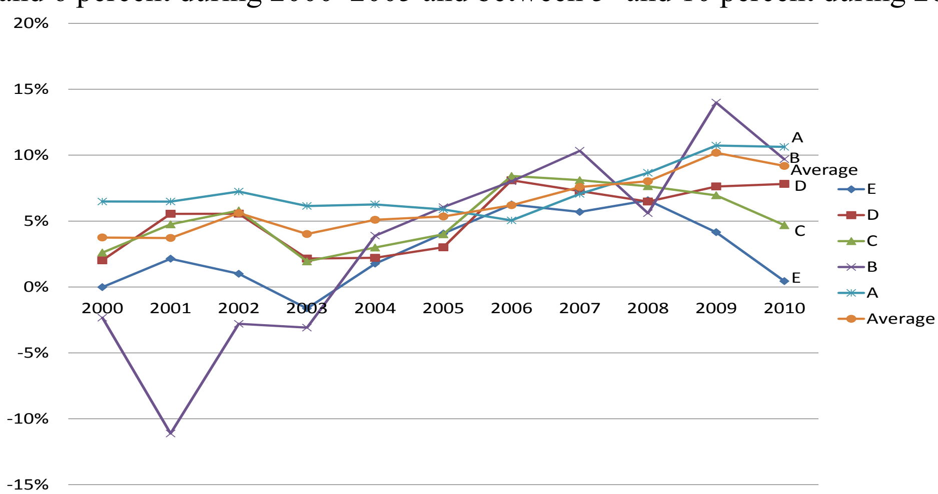


Figure 9. Equipment suppliers (n = 116, year 2010) – pre-tax profit margins during (2000–2010)

All five categories experienced positive pre-tax profit margins during 2004–2010. Group A's best years were 2009 and 2010, with pre-tax profit margins of 11 percent in both years. Group B's pre-tax profit margins were volatile during 2000–2010, with a peak in 2009 at 14 percent and 10 percent in 2010. Even though there are differences between the groups of companies over the year, due to market situations, the high value/high product complexity- proves to have the highest profit.

Figure 10 shows pre-tax profits per man-year for equipment suppliers during 2000–2010. Group A have experienced a rapid growth in pre-tax profits per man-year since 2005. In 2010, pre-tax profits per man-year were as high as NOK 0.45 million, more than four times the amount in 2005.

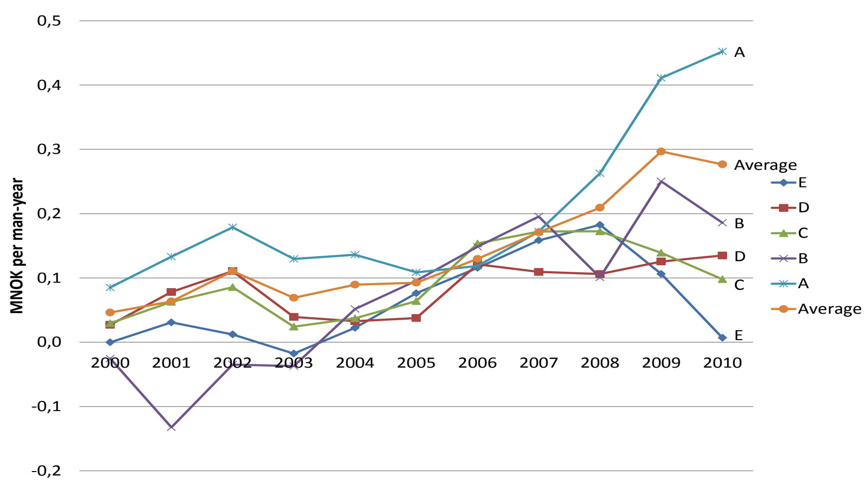


Fig 10. Equipment suppliers (n= 116, year 2010) Pre-tax profit per man-year (2000-2010)

Pre-tax profits per man-year for group B were volatile during 2000–2010. The peak was NOK 0.25 million in 2009 and the trough was NOK 0.19 million in 2010. Pre-tax profits per man-year for group C declined during the past couple of years, at NOK 0.10 million and NOK 0.17 million during 2010 and 2008, respectively. Group D had one of its best years in 2010, with pre-tax profits per man-year of NOK 0.13 million. Pre-tax profits per man-year for group E were volatile during 2000–2010; the best year was 2008 at NOK 0.18 million and then declined to NOK 0.01 million in 2010. Among the 116 supplier companies in the maritime industry, there is clear evidence that the firms with high competence intensity and high product complexity is the most profitable firms both with respect to profit margins and profit margin per man year.

4.4 The building of network as a dynamic capability

Sourcing has become one of the most critical activities of a manufacturing business. In ship-building, purchased good and services may constitute as much as 80% of the total cost of a ship. Not only is the sourcing process and positioning vital for quality and cost of the product but sourcing decisions affects the strategic positioning and thus the firms' competitive position of the firms in the network. It is a key strategic activity for achieving an innovative, high quality, great variety, low-cost and rapidly delivered end product.

With STX OSV's stand in the market as a reliable shipbuilder of highly specialised offshore vessels, the relationships to its vendors are important.
The analysis aimed to map STX OSV's relations to the company's different suppliers for in the next phase to act strategically different on the different supplier segments. To gain an overview of different suppliers' positions on STX OSV, two steps was undertaken.
First, the product groups were separated into different categories based on certain characteristics, which is discussed further in the next section. Thereafter each separate supplier and its position with respect to the company were evaluated**.**

4.4.1 Mapping products
The study built on the framework provided by Kraljic's purchasing portfolio matrix (Kraljic, 1983). The general idea of Kraljic's model is to minimize ".. supply vulnerability (risk) and make the most out of potential buying power.."(Kraljic, 1983, p 112).Kraljic's portfolio matrix categorises suppliers based on their supply risk and profit impact and the model has become the dominant approach to what the profession regards as operational professionalism (Gelderman & Weele, 2002).
There is no simple blueprint for the application of a portfolio analysis. It requires critical thinking and sophistication of purchasing management (Gelderman and Van Weele, 2003). Case studies have shown that measuring profit impact and supply risk in real life based on Kraljic's (1983) original framework is rather vague and diffuse (Gelderman and Van Weele, 2003). There are no explicit procedures for how to measure these variables present in Kraljic's (1983) framework. Gelderman and Van Weele (2003) identified in a study three different methods used for weighting the dimensions in the Kraljic portfolio matrix.
In this study a mixture of the weighted factor score method and the consensus method was used.
To evaluate these two dimensions, the following criteria were applied:

Supply risk:
- Product availability (20%)
- Number of potential suppliers (20%)
- Switch costs (20%)
- Consequence of delay (20%)
- Competitive structure (20%)

Profit impact:
- Economic impact (50%)
- Impact on end product quality (50%)

Table 3. Supply Risk and Profit Impact dimensions

By using the criteria and their respective weights as previously listed, the SFIs were ranked as follows in Table 4.

		Supply Risk						Profit Impact			
SFI	Description	Product availability	Nr. of potential suppliers	Switch cost	Consequence of delay	Competitive structure	**Average score**	Economic impact	Impact on end product quality	**Average score**	**Matrix category**
[illegible]	[illegible]	3	3	2	4	2	**2,8**	7	1	**4**	**NCI**
[illegible]	[illegible]	5	5	8	4	7	**5,8**	8	7	**7,5**	**SI**
[illegible]	[illegible]	4	4	5	5	5	**4,6**	5	7	**6**	**LI**
[illegible]	[illegible]	4	3	3	6	5	**4,2**	7	6	**6,5**	**LI**
[illegible]	[illegible]	1	2	2	2	2	**1,8**	7	6	**6,5**	**LI**
[illegible]	[illegible]	7	7	8	8	5	**7**	9	9	**9**	**SI**

Table 4 Outline of ranking procedure [8]

[8] SI = Strategic items, LI = Leverage items, BNI = Bottleneck items, NCI = Non-critical items.

By following this procedure, each product group was assigned a specific score for the two variables of supply risk and profit impact. Using these data, the results were plotted in a matrix corresponding to that of figure 17, the actual matrix:

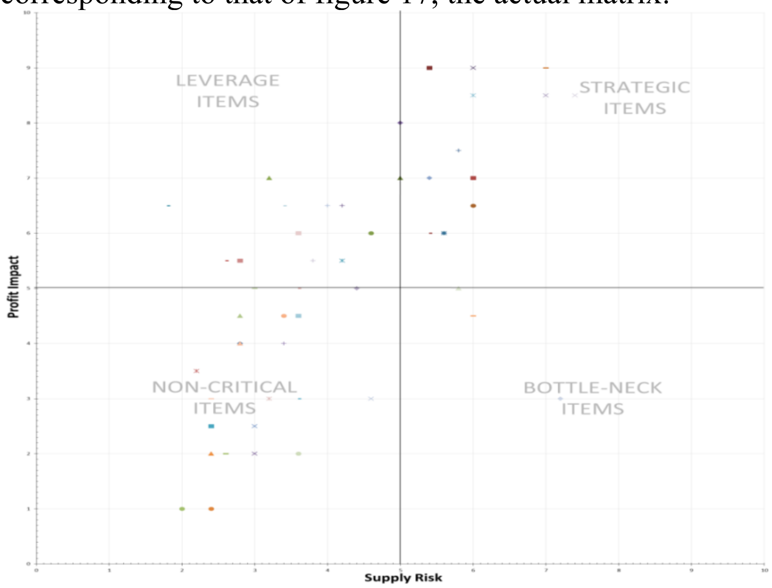


Figure 11. Kraljic's matrix STX OSV

Figure 11 illustrates the categorisation of all purchased products and services of STX OSV based on the level of supply risk and the degree of profit impact.

Summary statistics	Strategic Items	Leverage Items	Bottleneck Items	Non-critical Items
Number of SFIs	16	13	2	21
Total number of suppliers	50	45	3	52
Suppliers per SFI				
Average	3,33	3,46	1,50	2,48
Median	3,00	2,00	1,50	2,00
For product group				
Purchase volume (tNOK)	3 948 335	533 553	10 869	250 253
Share of total purchase (%)	83,25 %	11,25 %	0,23 %	5,28 %

Table 5 Descriptive statistics of STX OSV purchases

Table 5 shows the descriptive statistics of the results. Based on the previous ranking and categorisation[9] and the following statistics derived from such, several key findings were derived. The key findings using Kraljic's methodology are as follows:

More than 83 % of purchased value of the SFIs were categorised as strategic items to the company. 40% of the SFIs are classified as non-critical items, but they make up only 5 % of total purchases.

In addition to this study done on a product/SFI bases, two corresponding studies was done on supplier level, one of them being a traditional ABC analysis. Both analyses primarily supported the findings from Kraljic's matrix in that suppliers of strategic items are of high strategic importance.

[9] Key findings are also derived using more specific graphs and overviews not presented in this analysis.

The findings are consistent with them saying that co-creation of value calls for focal companies to act strategically different on their suppliers and that no organisation can create value in isolation (Defee and Fugate, 2010). Strategies attached to different categories like strategic suppliers should be managed through close partnerships, relations or acquisitions; Bottleneck suppliers through long term contracts, cooperation or other business models; and Leverage Items through development of creative strategic partnerships and active sourcing (Gelderman and Van Weele (2005), Caniels & Gelderman (2005), De Boer et al. (2001).

In this case study the focal company has shown how they value their vendors. Nearly 85 % of the product purchased value was classified as strategic and almost 90% of the suppliers of strategic items were classified as AA suppliers (high value and high importance). The focal company takes on a leading role in involving multiple players in the co-creation of value process. Few or none of them should be kept on arm's length distance. On the contrary, supplier development and strategic partnering is constantly more important in high value manufacturing network. The development and management of a high value manufacturing network is a network dynamic capability.

5. Conclusion and implication

In this paper the understanding of inter- firm relationships as critical element of a high value production network, was pursued. The arena was the maritime cluster of Møre and Romsdal, Norway. Both through qualitative and quantitative data the relationships were proven significant.
The importance of the relationships between all the different groups of actors as expressed was strong. The espoused expressions were proven right when we analysed the actual financial streams between the actors. Almost 40% of the supply was sourced from suppliers within the county and almost 65% was sourced from Norwegian suppliers. The cluster proved to be a high value manufacturing network. Innovative, high value products of system character evidently require a well-functioning network structure to be competitive.

Within an internal sourcing and value chain reconfiguring project we analysed where the value was captured in the network, and concluded that the companies with highest knowledge intensity and highest product complexity were the most profitable.
Through a case study of a leading actor in the cluster we got insight into the involvement of multiple organisations into the co-creation of value process. Assessed according to the two dimensions, profit impact and supply risk, 83 % of the value of the products were categorized as strategic items and 90% of the suppliers of strategic items were ranked as AA suppliers. This means that the company are engaged- or will engage in processes of supplier development and strategic partnering. This meaning closer network relationships.
High value producing network have proven competitive. It's a way of co-creating value in a governance structure outside the market and outside the hierarchy. As seen in many industrial districts or cluster there are elements that are reinforcing both the cluster and the competitiveness of the cluster. Network as a process of involving multiple organisations in working together is not only a necessity in high value producing network. Building bridges and close relationships between organisation should be seen as a dynamic network capability, - a capability of the network.
Research on external dynamic capabilities have been scarce but should be offered more research attention. (Alinaghian et al. 2012). Hopefully this study is a small contribution both to the understanding of network in high value manufacturing and to the dynamic capabilities of building network.

More research should be done on different clusters to compare both extent of relations and kinds of relations. Further, more research should be done on revealing the strategic partnering and network building on both sides of the network dyads.

References:

Alinaghian, L.S., Srai, J.S. & Sir Gregory, M. (2012). Operatonalising Dynamic Capabilities; A Supply Network Approach, Paper at DRUID

Argyris, C. & Schön, D.A. (1974). Theory in Practice: Increasing Professional Effectiveness. San Francisco: Jossey-Bass.

Barney,J.B. (1991). Firm resources and sustained competitive advantage. Journal of Management 17, 99-120.

Basole, R.C. & Rouse, W.B. (2008). Complexity of service value networks: Conceptualization and empirical investigation. *IBM System Journal*, 47 (1), 53-70.

Bellandi, M. (1989). "The Industrial District in Marshall." Goodman, E. and Bamford, J. (eds) 1989. Small Firms and Industrial Districts in Italy. New York. Routledge: 136-152.

Bozarth, C.C., Warsing, D.P., Flynn, B.B. & Flynn, E.J. (2009). The impact of supply chain complexity on manufacturing plant performance. *Journal of Operations Management, 27*(1)*,* 78–93.

Caniels, M. & Gelderman, C.J. (2005). Purchasing strategies in the Kraljic matrix, A power and dependence perspective, *Journal of Purchasing and Supply Management,* 11(2–3), pp. 141–155.

Chen, I.J., Paulraj, A. & Lado, A. A. (2004). Strategic purchasing, supply management and firm performance. *Journal of Operations Management*, 22(5), 505-523.

Choi, T.Y., Dooley, K.J. & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management, 19*(3)*,* 351–366.

Cohen, M.A., Agrawal, N. & Agrawal, V. (2006). Winning in the Aftermarket", *Harvard Business Review*, 84 (5), 129–138.

Corsaro D., Ramos C., Henneberg S. & Naudè, P. (2012). The impact of network configurations on value constellations in business markets — The case of an innovation network. *Industrial Marketing Management*.

Davies, A., Brady, T. & Hobday, M. (2007). Organizing for solutions: systems seller vs systems integrator, *Industrial Marketing Management* 36 (2007) 183–193.

De Boer, L., Labro, E. & Morlacchi, P. (2001) A review of methods supporting supplier selection. *European Journal of Purchasing & Supply Management,* 7(2):75-89.

Defee, C.C. & Fugate, B.S. (2010). Changing perspective of Capabilities in the dynamic supply chain era, The International Journal of Logistics Management.

Farstad Shipping ASA (2012) Annual Report https://www.farstad.com/en/annualreport2012/downloads

Ford D., Gadde L. E., Haakansson H., Lundgren A., Snehota I., Turnbull P. & Wilson D. (1998). *Managing Business Relationships*. Chichester (UK): Wiley.

Halse, L.L. and Bjarnar, O. (2011), "Cluster transformation from a supply chain perspective: Theoretical models and the case of the maritime cluster in mid-west Norway". *Regional Studies Association Annual International Conference*, at Newcastle.

Hervik, A. and Jakobsen, E.W. (2001), *Det regionale maritime Norge: en vital nasjonal næring med regionale særpreg,* Handelshøyskolen BI, Oslo.

Humprey, J. & Schmitz ,H. (2002). How does insertion in global value chains affect upgrading in industrial clusters? Regional Studies, 36(9), 1o17-1027.
Håkansson, H. & Snehota, I. (2006). No business is an island: The network concept of business strategy. *Scandinavian Journal of Management*, 22 (3) 256-270.
Gelderman, C. J. & Van Weele, A. J. (2003). Handling measurement issues and strategic directions in Kraljic's purchasing portfolio model. *Journal of Purchasing and Supply Management,* 9(5-6):207-216.
Gelderman, C. J. & Van Weele, A. J. (2005) Purchasing Portfolio Models: A Critique and Update. *Journal of Supply Chain Management,* 41(3):19.
Gereffi,G., and Fernandes- Stark, K.(2011). Global Value Chain Analysis: A primer. Durham, North Carolina: Center on Globalization, Governance and Cometitiveness (CGGC)- Duke University.
Gereffi, G., Humprey, J., & Sturgeon, T. (2005). The governance of global value chains, Review of International Political Economy, 12(1), 78-104.
Kraljic, P.(1983). Purchasing Must Become Supply Management. *Harvard Business Review,* 61(5):109.
Matthyssens, P., Vandenbempt, K. & Weyns, S. (2009). Transitioning and co- evolving to upgrade value offerings: A competence-based marketing view. *Industrial Marketing Management*, 38 (5), 504-12.
Moller, K. E. K. and Torronen P. (2003). Business suppliers' value creation potential: A capability-based analysis, *Industrial Marketing Management*, 32, pp. 109-118.
Möller, K., Rajala, A. & Svahn, S. (2005). Strategic business nets—their type and management. *Journal of Business Research*, 58 (9), 1274−1284. Möller, K., & Svahn, S. (2003). Managing strategic nets: a capability perspective. *Marketing Theory*, 3 (2), 209−234.
Normann, R., Rafael Ramírez , R. (1993) From Value Chain to Value Constellation: Designing Interactive Strategy. *Harvard Business Review, Vol. 71, Issue 4*
Normann, R., & Ramirez, R. (1994). *Designing interactive strategy: From the value chain to the value constellation*. Chichester: John Wiley & Sons.
Oterhals, O, Johannessen, G and Hervik, A. (2011). *STX OSV. Ringvirkninger av verftsvirksomheten i Norge*, *Rapport 1108, Møreforsking Molde, Molde.*
Pathak, S.D., Day, J.M., Nair, A., Sawaya, J. W. & Kristal, M. M. (2007). Complexity and Adaptivity in Supply Networks: Building Supply Network Theory Using a Complex Adaptive Systems Perspective, *Decision Sciences Volume 38 No 4.*
Peppard, J.& Rylander, A. (2006). From Value Chain to Value Network: Insights for Mobile, Operators, *European Management Journal Vol. 24, Nos. 2–3, pp. 128–141.*
Porter, M.E. (1990). The competitive advantage of nations*, Macmillan, London.*
Porter, M.E. (1998). Clusters and the new economics of competition, *Harvard Business Review, Vol 76, No.6, pp.77-90.*
Reve, T., Lensberg, T. & Grønhaug, K. (1992). A competitive Norway*, Tano, Oslo.*
Rudberg, M. & Olhager, J. (2003) Manufacturing networks and supply chains: an operations Strategy perspective, *Omega 31,29 – 39.*
Rudberga, M. & Martin, B. (2008). West,Global operations strategy: Coordinating manufacturing networks*, Omega 36, 91 – 106.*
Sakuda, O.L- and Fleury, A. (2012). Global Value Chains, Global Production Networks: Towards "Global NetChains" Synthesis?m Paper presented at Cambridge International Manufacturing Symposium 2012.

Shi, Y. & Gregory, M. (1998). International manufacturing networks—to develop global competitive capabilities, *Journal of Operations Management 16, pp195–214.*

Srai, J. S. & Gregory, M. (2008) A supply network configuration perspective on international supply chain development, *International Journal of Operations & Production Management Vol. 28 No. 5, pp. 386-411.*

Staber, U. and Morrison, C. (1999). The Empirical Foundations of Industrial District Theory, Presented at the ISRN Workshop on Globalization and Regional Innovation Systems, Toronto, May 17-19.

Sturgeon, T., Van Biesbroeck, J., & Gereffi, G. (2008). Value chain, networks and clusters: reframing the global automotive industry. Journal of Economic Geography, 8(3), 297-321.

Tan, C. K. 2001).A framework of supply chain management literature, *European Journal of Purchasing & Supply Management 7, 39}48.*

Teece, D.J. (2007). Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28 (13), 1319-135

Teece, D.J., Pisano, G. & Shuen, A. (1997). Dynamic capabilities and strategic management", *Strategic Management Journal*, 18 (7), 509–533.

Van Weele, A. J. (2005). *Purchasing & supply chain management: analysis, strategy, planning and practice.* 4th London, Thomson.

Vargo, S.L., & Lusch, R.F. (2011)- It's all B2B...and beyond: Toward a systems perspective of the market, *Industrial Marketing Management*, 40 (2), 181-187.

Wilding, R. (1998) The Supply Chain Complexity Triangle: Uncertainty generation in the supply chain*, International Journal of Physical Distribution and Logistics Management, vol 28, No.8, pp 599-616.*

Windahl, C. and Lakemond, N. (2006). Developing integrated solutions: The importance of relationships within the network. *Industrial Marketing Management*, 35 (7), 806–818. Windahl, C. & Lakemond, E. (2010). Integrated solutions from a service-centered perspective: Applicability and limitations in the capital goods industry. *Industrial Marketing Management*, 39 (8), 1278-1290.

Yin, R.K. (1994). *Case study research – design and methods*. Sage: Thousand Oaks, CA, USA.

Low Carbon Emission Supply Networks: Starting from Carbon Footprint Measurement

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Abstract
Climate change is regarded as a tropical issue facing by different aspects of human society, with efforts focus on building, traffic and manufacturing industries. Some proactive organizations and firms start to transformation while the Low Carbon Emission Network is still at its infancy. According to several case study, this work concluded the first step of low carbon emission supply network transition—measurement of carbon footprint, answering the industrial challenge: how to measure the carbon emission on supply network level? A process analysis of "point of entry, participation, procedure, project and process management" is applied and a practical measurement process is proposed. Supplier engagement and internal capability building are identified as the key factors. The measurement process tailored according to the degree of accuracy is consistent to the priority of the aims of carbon reduction related action, and relevant to the influence strategy mentioned above.

Keywords: carbon footprint measurement, life cycle assessment, performance measurement, process design

1.Introduction

Significant movement is expected towards sustainable manufacturing industry development as the environmental, social issues increasingly become factors to be considered by companies' strategy makers. Manufacturing sustainability will increase both opportunities and risks to manufacturing firms. CSR reports of companies become a must for big brands and the list of companies attending environmentally and socially concerned improvement is enlarging. Among the issues in sustainability, the carbon emission is the hottest and discussed heavily. According to BSI (BSI 2008), GHG emissions frequently arise from supply chain within business, between business, and between nations. Of the humanity's 50,000 mega-tonnes of annual CO_2e greenhouse gas emissions, around 2,800 mega-tonnes can be assigned to the logistic and transport activities-the major part of supply chain. It seems possible that significant emissions reductions could be achieved in the medium term by implementing change throughout the end-to-end supply chain. Nations and governments all over the world have established or planned to establish legislations for carbon emission reduction. Except for the huge pressure from governing body, the manufacturing firms also face the volatile energy prices and cost for waste management. Among all the reasons, the most direct one would be the customer requirement for environmental friendly products for those who are running B2B (Business to Business) mode. ICT industries are widely affected by this trend as their clients from Europe and the States directly send out requirements for the carbon footprint of their products. LCA (Life Cycle Assessment) is the key methodology in the measuring the product carbon footprint, starting from the original raw material extraction to after-sales disposal. The auditing of product carbon footprint provides an opportunity for companies to initially monitor different parts along their supply chain, including sourcing, inbound logistics, production, outbound logistics, and customer usage. The auditing process helps the companies to gain the mapping of supply chain carbon emission performance and identify potentials in decarbonlization of their operations. This paper tries to identify the key categories and sub-categories along the value chain in carbon emission reduction potentials, presenting a matrix as the low carbon emission supply chain framework. A case company in ICT industry is examined for their carbon footprint measurement process and also the practices in greening their product's life cycle performance. The study shows that carbon footprinting should be first step to start carbon management, and the cooperation along the supply chain plays a great impact to the total performance of production carbon emission.

2.Practical and Literature Review

Carbon Footprint and Measurement Standards

As generally recognized that only the measurable get managed, it is well regarded that a standardized method to measure and report the carbon emission profile becomes a must (Pandey, 2011, carbon footprint: current methods of estimation; Rebitzer, 2004, life cycle assessment-part 1: framework, goal and scope definition, inventory analysis and applications; Laurent, 2010).

Despite wide use, the term carbon footprint seems to have no clear definition (Wiedmann and Minx, 2008). Based on a review of its use in literature Wiedmann and Minx (2008) propose the following definition:

> "The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

This definition brings in a lot of argument since researchers argued that all greenhouse gas emissions should be included which include all greenhouse gas emissions (Baldo, Marino, Montani, and Ryding, 2009; Iribarren, Hospido, Moreira, and Feijoo, 2010; Plassmann et al., 2010; Weidema et al., 2008; Wiedmann,2009). In Kyoto Protocol six greenhouse gas emissions are identified as the main emission control targets. In our research, we regard the carbon footprint includes the six key GHG according to Kyoto Protocol, expanding the Wiedmann's definition. The carbon footprint concept has been applied to many levels, including products, households, companies, cities and regions, and countries (Peters, 2010). We define in this study that the carbon footprint on the product level as CFP (Carbon Footprint of Products) in our research as defined by ISO(ISO14067 Draft, 2012) and we defined PCF as the abbreviation of the action of calculating/obtaining the CFP--Product Carbon Footprinting.

Surprisingly different from Green issues, the discussion of PCF (Product Carbon Footprinting) is limited in number in the operations and supply chain journals. Both Jensen (2012) and Sundarakani (2010) concluded that the publications of modeling/measuring carbon emissions are much fewer in SCM and operation management compared to Green SCM.

The wording of Carbon Footprinting comes from the 'Ecologcial Footprint' research in the 1990s (WBCSD, 2010 "Vision 2050, the new agenda for business"; Wackernagel, 2004, ecological footprints and energy). But the methodologies adopted for performing PCFs originate from the life cycle assessment/analysis (LCA) literature.

Wiedmann and Minx (2008) specify Life Cycle Assessment (LCA) as the appropriate method for calculating a carbon footprint. Though recommending that the definition and method of carbon footprint should be kept separate, Peters (2010) identifies LCA as the appropriate approach for measuring the carbon footprint of consumer products. The International Standards Organization (ISO) working group identified a number of core questions regarding standardization of the quantification of carbon footprints, and even in the relatively easy class of LCA needed for carbon footprints there is no easy solution to the identified questions (Finkbeiner, 2009).

The demand for carbon footprint information and the need for further principles and techniques have lead to a number of international, national, and sectoral initiatives (Finkbeiner,2009). Plassmann et al. (2010) identified more than thirteen different methodologies for product carbon footprinting under development in 2009. According to the degree of specification, Carbon footprint measurement methodologies can be classified into three different main groups (Baldo et al., 2009):

- General guidelines, such as ISO standards, that represent the normative standard references for CO2 calculation.
- Specific guidelines, such as PAS 2050, that contain ad hoc indication on GHG calculation and monitoring.
- Calculation tools that are aimed at calculating CO2

The British Standards Institute's (BSI) Publicly Available Specification (PAS) 2050 represented the first standards for measuring the carbon footprint of products when released in 2008 (Wiedmann, 2009), as well as some other ongoing standardization efforts such as the WRI/WBSCD's Greenhouse Gas Protocol Scope 3 standards and the ISO 14067 standards (Wiedmann, 2009), ILCD Handbook(Jensen 2012), etc.. ISO

14067 is still under development (expected to reveal on 2014) and based on ISO 14040 and ISO 14044, serving PAS2050 as the seed document. So we will not consider ISO14067 in the following comparison section.

The LCA methodology dates back to the 1970s (Seuring, 2004, Industrial ecology, life cycle, supply chains: differences and interrelations; Wiedmann,2009, carbon footprint and input-output analysis-an introduction). Some researchers argue that carbon footprinting is a subset of LCA because only green house gas are counted in the carbon footprint (Bala,2010, Simplified tools for global warming potential evaluation; Sinden, 2009,The contribution of PAS 2050 to the evolution of international greenhouse gas emission standards; European Commission, 2010, ILCD handbook; WRI and WBCSD, 2010, the greenhouse gas protocol: product accounting & reporting standard--GHG protocol; Schmidt H.J., 2009,Carbon accounting and carbon footprint–more than just diced results?) or even a simplified application of LCA (SETAC, 2008, Standardisation efforts to measure greenhouse gases and 'carbon footprinting' for products).

The Comparision Between PCF Methods

Standards are regarded an important tool for measuring and reducing GHG emissions from supply chains (Jensen,2012). As we mentioned above there are several standards exist for the PCF process. Jensen gives out the following critirias to compare them: the unit of analysis, the type of PCF, the modelling framework, data timeframe, data sources and the handling of the multifunctional problem. The standards summarized are ISO14040/ISO14044, PAS2050, ILCD and GHG Protocol Scope 3 standards. The following table shows the results of comparison.

Table 1 Comparisons and Conclusions in Different Standards

Analysis Category	Options	Explaination and key points
Unit of Analysis (in the Standard)	the funcional unit of product	1.Enable the comparison of different products 2.it is a natural step to identify actors in supply chain
Standard Type	Bottom-up analysis	1. Data usually collected from individual processes (Peters,2010) 2.Under some special conditions IOA type dataset could also satify the requirement (but the standard leaves a gap here to guide users combining the process-based method and IOA
Modelling Framework	Attributional or Consequential	1. For Accounting Purpose--Attributional is preferred 2.For decision making purpose-- Consequencial aproach is preferred using short-term and long-term marginal data 3.Combined approaches are required when determining effects on the economy.(European Commission,2010,ILCD)
Data Sources	Primary data for processes owned, operated, or controlled by focal company	1. Primary data is preferred except the ISO14040 accepts legitimate data 2. Data from upstream/downstream supply chain actors: PAS2050--accept secondary data from suppliers; ILCD--requires primary data from suppliers as well
Timeframe	historial, fact-based, measurable data	Due to the attributional
multifunctional process	economic allocation, physical relationship allocation	very similar between standards

As stated in the table, in most sections the standards have similar settings and suggestions. PAS2050 is the first public available guidelines specialized on GHG emissions, rather than general environmental footprint assessment standards (such as ISO14040, ILCD, etc.). And a few pioneering companies have taken the first step on PCF using/building up PAS2050. Consequentially PAS2050 is more broadly used among companies globally compared to WRI&WBCSD's Product Standard. So in our research we focus on the application process of PAS2050 in case companies, and our analysis is focus on this standard as well. The following section illustrate the inner relations between CFC (Carbon Footprint of Corporate) and CFP (Carbon Footprint of Product) and detailed the PAS2050 methodologies.

The Carbon Footprint of Corporate and of Product

CFC (Carbon Footprint of Corporate) and CFP (Carbon Footprint of Products) are two key activities when firms are tackling the carbon issues. Considering firm as a input-output system, the semi-product going through the system—the firm—get manufactured/processed, while the processes involve energy, material and waste generated, generating GHG emissions. And at the same time outside the key processes, the supporting activities to these processed within the system also generate carbon emission as well. If we look at the system within the firm's boundary, the key processes within the plant and the supporting processes are both included. But following the product lines, only the key processes will be counted and the relevent emission will allocated to the product. So the CCF (Corporate Carbon Footprinting), such as IPCC/GHG protocol, is targeting the first type of measurement of carbon emission of the system, and PCF (Product Carbon Footprinting), the life cycle assessment type method, such as PAS2050, ISO14067, is targeting the second type.
Both of the methods can be de-assemblied to a basic formula, which is the amount of used Energy/Rourses/Waste multiple the conversion factor (CO2 emission/unit). The difference between the CCF and PCF is as follow: The CCF covers all the processes within one corporate, while the PCF covers the key processes along the whole manufacturing chain of the specific product, and allocate the ERW related carbon emission to a single product. So the scientific way to do the allocation is also a key part of PCF.

The PCF, if eliminated some non-important processes, shrinking boundaries and reducing the up-stream or down-stream relevant stages, could be conducted as so-called streamlined LCA method. The Input-Output methodology in Economics are also used to calculate the Carbon Emission, especially suitable for the country, industry and area level. Some researchers do study in the Economic Input-Output LCA (EIO-LCA)Analysis of Carbon Emission. Both streamlined LCA and EIO LCA have the shortfalls in the uncertainty and accuracy of PCF result, but with lower cost and time invested. So they are also considered as proper or sometimes efficient PCF methods in different contexts. The next section will detail more on the different LCA methodologies.

Public Available Specification 2050 (PAS 2050) and Life Cycle Assessment

PAS (Publicly available specification), 2050 which is developed by Carbon Trust, Department of Environment Food and Rural Affairs (Defra), and British Standard Institute (BSI) in 2008, is a specification for the assessment of the life cycle greenhouse gas emissions of goods and services.

PAS 2050 was developed in reply to a broad community and industry need for a consistent method for measuring the life cycle GHG (Green House Gases) emissions. It was built based on existing life cycle assessment methods established through standards BS EN ISO 14040 and BS EN ISO 14044(Carbon Trust, 2008). Many companies have already joined PAS 2050, including PepsiCo, Boots, Innocent, Marshalls, Tesco, Cadbury, Halifax, Coca Cola, Kimberly Clark, The Co-operative Group, Scottish & Newcastle, Coors Brewers, Müller, British Sugar, ABAgri, Sainsbury's, Danone, Continental Clothing Company, Colors Fruit, Morphy Richards, Mey Selections and Aggregate Industries. (Carbon Trust, 2008).In 2011 the PAS 2050 is further revised after practised in some companies. According to Carbon Trust, the PAS 2050 provides the following benefits:

*For organizations that supply goods and services, the PAS:

-allows internal assessment of the existing life cycle GHG emissions of goods and services;

-facilitates the evaluation of alternative product configurations, sourcing and manufacturing methods, raw material choices, and supplier selection on the basis of the life cycle GHG emissions associated with goods and services;

-provides a benchmark for ongoing programmes aimed at reducing GHG emissions;

-allows for a comparison of goods or services using a common, recognized and standardized approach to life cycle GHG emissions assessment; and

- supports reporting on corporate responsibility.

* For consumers of goods and services, the PAS:

- provides a common basis for reporting and communicating the results of life cycle GHG emissions assessments that supports comparison and uniformity of understanding; and

- provides an opportunity for greater consumer understanding of life cycle GHG emissions when making purchasing.

PAS 2050 is intended for both product comparisons and communication of this information,but does not specify requirements for communication. PAS 2050 specifies that LCA shall be used to assess the GHG emissions of products. The specification distinguishes between business-to-consumer assessments, which employ a cradle-to-grave approach, and businessto-business assessments that employ a cradle-to-gate approach. Additionally, it does not include product category-specific rules, but is intended that these can be developed in accordance with ISO standards and will be adopted by the standard when available.

Carbon Trust Carbon Reduction Label

The PAS 2050 standard recognizes a wide range of potential uses for the information on the carbon footprint of products, but does not provide requirements on the use of the assessments that arise from implementation of the specification (Sinden, 2009). It does not explicitly support comparative assertions, but recognizes that individual stakeholders may compare results that are placed in the public domain (Sinden, 2009). The Carbon Trust offers a labeling service by its subsidiary consultancy firm 'Carbon Footprint Expert' that allows firms to communicate the carbon footprint of their product, which would allow for comparative assertions. The label was based on the original carbon footprint methodology developed by the Carbon Trust (Carbon Trust, 2007).

In a 2009 review of product carbon footprint schemes the Carbon Trust Carbon Label was by far the largest of the twelve operational programs for product carbon footprints, with 2,000 certified products (Bolwig and Gibbon, 2009). The Carbon Trust claims more than 5,000 products carry the label and that it is one of the largest eco-labels in the U.K.(Carbon Trust, 2011).

Life Cycle Assessment

Life Cycle Assessment method is the base of PAS2050, a quantitative process for evaluating the total environmental impact of a product over its entire life cycle, referred to as a cradle-to-grave approach. LCA is product focused, with emphasis on quantifying the environmental impacts (Heijungs, 1996).

LCA, as defined by the ISO, consist of four phases:

1. Goal Definition and Scope.

2. Inventory Analysis.

3. Impact Assessment.

4. Interpretation.

In some instances only phases two and four need to be performed, in which case this is referred to as a Life Cycle Inventory (LCI) (ISO, 2006a). The goal definition and scope phase includes identifying the product or function being studied, the reasons for carrying out the study, defining the system boundary, and identifying the data requirements. Inventory analysis involves identifying the process involved in the system, defining the inputs and outputs of each process, and collecting data to quantify those inputs and outputs. Impact assessment defines impact categories and used the results of the inventory analysis to calculate indicator results in those categories. Finally, in the interpretation phase, the results of the inventory analysis and impact assessment are interpreted in terms of the goal and scope definition; the results are checked for completeness, sensitivity, and consistency; and conclusions, limitations, and recommendations are reported (ISO, 2006a).

LCAs generally fall into two categories based on their purpose. An attributional LCA is focused on looking back on a product and determining what emissions can be attributed to it. A consequential LCA is focused on the environmental effects of what will happen due to a decrease or increase demands for goods and services (Ekvall and Weidema, 2004). The two types of LCAs are suitable for different purposes and require different types of data. An attributional LCA is appropriate for making specific environmental claims regarding a product, and typically makes use of average data for the product. The consequential category is more suited to performing scenario analysis. It often requires marginal data for the product as it requires making assumptions about economic factors related to changes in product consumption or production (Tillman, 2000).

In addition to the types of LCA there are two main LCA methodologies: a process-based approach and an Economic Input-Output (EIO) approach. In a process-based methodology all phases of a product are examined and their inputs and outputs are mapped. This is typically considered the conventional method of LCA, and is sometimes referred to as the ISO or SETAC method (Lenzen, 2001). The EIO-LCA approach uses broad economic categories to provide environmental impacts, but generally only includes the production phase. The two methods can also be combined to form a hybrid approach (Suh et al., 2004).

The Limitations of Two LCA methodologies and their application scenario

Life Cycle Assessment provides a general framework for measuring the environmental burden of a product or function. Its general structure allows application to a wide variety of items, but also allows considerable freedom in implementation. This freedom makes for difficulty in comparison between any two separate LCAs. Previous work has highlighted this lack of standardization in some important areas of Life Cycle Assessment, including defining system boundaries (Tillman, Ekvall, Baumann, and Rydberg, 1994)(Suh et al., 2004) and allocation methods (Ekvall and Finnveden, 2001)(Ekvall and Weidema, 2004). This lack of standardization means that while LCA provides a methodology for measuring a carbon footprint, the results of two studies may not be comparable.

Process-based LCAs have also been criticized for reasons related to their data requirements (Hendrickson et al., 1997). The high cost and time of performing process-based LCAs poses difficulties for products with complex supply chains spanning many organizations. A survey of LCA practitioners identified data collection as the most time consuming and costly aspect of performing an LCA (Cooper and Fava, 2006). Collecting data across organizational boundaries presents issues with proprietary and confidential information, data accuracy, and a lack of representative data (Chevalier and Teno, 1996)(Huijbregts et al., 2001).

EIO-LCA provides an approach that requires less detailed process data. This work builds upon the original EIO work of Wassily Leontief (1986), who developed the method for economic study. This method makes it possible to describe the output of one industry sector in terms of the inputs required from other sectors to produce it. By assuming a linear proportionality, any dollar value of output can then be expressed in the dollar values of inputs from other sectors required to produce it. The EIO-LCA model expands on this by adding the environmental burdens linked to industry sectors (Joshi, 2000). Together this can be used to determine the total environmental burden of an industrial sector per dollar of sector output.

An EIO approach has several advantages over a process-based LCA. By including all upstream activity within the economy the data is more complete, and there is no need to draw system boundaries. The data is generally compiled from publicly available sources, allowing for greater transparency than process-based LCAs that use proprietary data. Finally, the EIO approach allows a much cheaper and faster method of providing results. In cases where only an approximate result is needed an EIO LCA can provide a very rapid and inexpensive answer (Hendrickson, Horvarth, Joshi, and Lave, 1998).

The assumptions and methods of EIO analysis do have drawbacks for determining the environmental burdens of a specific product. Though EIO tables may contain hundreds of sectors, this still requires significant aggregation of different products and processes. Some sectors may be too heterogeneous to produce correct results (Hendrickson et al., 1998). The information in the Input-Output tables only captures the effects of production and therefore the use and disposal phases are not included (Joshi, 2000). Many countries lack the sectoral environmental data needed for analysis, meaning that imports must be assumed to be homogeneous with domestic products (Suh and Huppes, 2005). Finally, the nature of Input-Output analysis assumes proportionality between monetary and production flows(Lenzen, 2001). That is, if a product doubles in cost then the environmental burden doubles as well. Though necessary for the computational results this may not reflect the reality of the production process.

In an attempt to build on the strengths of process-based and EIO-LCAs a third method has emerged, a hybrid of the two (Suh and Huppes, 2005). The hybrid method uses a detailed processed based methodology for the important foreground processes and an EIO model to fill in the background processes (de Haes, Heijungs, Suh, and Huppes, 2004). The use of a hybrid method allows the EIO method to be used to inexpensively provide complete data for the less important parts of the system, while using the more detailed and specific process data for the most important parts. In order to perform a hybrid LCA it-is necessary to determine the boundaries between the EIO and process-based systems. Poorly selecting these system boundaries can introduce significant error (Suh and Huppes, 2005). Hybrid LCAs may also involve some double counting, as portions of the process-based LCA may have been included in the 10 data. However, this may still produce more accurate results than a pure process-based LCA that draws system boundaries and ignores processes which occur outside of the system (de Haes et al., 2004).

Low carbon footprint supply chain management

Carbon footprint problem is the outstanding and hot topic in green supply chain management. Carbon emission control reflects the waste control issue in green supply chain, and it is relatively easy to measure, and straight forward. Solving the carbon emissions control problem across the supply chain will bring in insight to the other pollution prevention mechanism in supply chain management. And the industrial needs for carbon control calls for strong resolution in supply chain level. And although there already are initial attempts of controlling carbon footprint across supply chains, a better understanding of the carbon flux in supply chains is critical as carbon emissions and carbon constraints "can financially affect a company even if they occur not in the company itself, but within the value chain of the company."

Despite a lot of research effort in Green Supply Chain Management, the supply chain and operations management literature is scare with respect to carbon footprint reduction. Sundarakani discuss how carbon footprint across supply chains can be measured, and the modelling of the process (Sundarakani et al. 2010). Wu propose a model that captures the behaviour of power generators with a portfolio of power plant potions and subject to pollution taxes within the context of supply chain networks for electric power (K. Wu et al. 2006). Cholette and Venkat calculate the energy and carbon emissions associated with the transportation links and warehousing activities in food and beverage supply chains, particularly in wine industry (Cholette & Venkat 2009).

One case study in the research of Sundarakani (Sundarakani et al. 2010) shows that 25% of the carbon emissions come from the supplier, 22% from the logistics, 40% from the manufacturing plant and 13% from the warehouse/distribution centre. The manufacturing plant and supplier side emissions are higher in this case because it is automotive company in which supply chain processes and assembly lines consumes more energy than other industries. The configuration factors of network design, such

as suppliers, logistics, and distribution contribute a lot to the carbon emissions. This provides a reason to study carbon emission reduction in supply network level.
Sundarakani tried to model carbon footprints across the supply chain (Sundarakani et al. 2010). He makes the statement that better understanding to the heat flux in supply chains is critical which transform the carbon emission control to heat flux analysis. A model of heat flux through a node is given out. Based on the factors in this model, numerical analysis employing Eulerian and Lagrangian transport models is produced to calculate the emissions. This model can be used to calculate the carbon footprint of each stages across the supply chain, including suppliers, logistics, plant and warehouse.

However, the calculation can only be established under estimated parameters, and it has not point out carbon footprint reduction methods.
Sundarakani also gave out system specification in each stages of the supply chain, "At the supplier stage, the processing of raw material and preparing the semi-finished parts emits….At the stage of logistics service provider, the levels and types of carbon emissions depend on the mode of transportation, choice of fuel used, and distance travelled…at the stage of manufacturer can be measure from direct and indirect emissions…at the stage of distribution centre (warehouses) depend on the type of packaging used, trade policy, consumer density, and the level of reuse"(Sundarakani et al. 2010). This specification also points out the elements affecting carbon footprint in the supply chain.

Carbon Footprint reduction initiatives

From the preliminary industries practices review the primary conclusion can be draw that carbon footprint reduction could be primarily achieved by through wider adoption of available technologies, leveraging new business relationships and developing new business strategies. The possible opportunities to address carbon emissions across the product life-cycle may outlined as follow.

- Increasing the efficiency of vehicles in daily operation and switching to alternative or hybrid fuel technology sources;
- Slowing down the supply chain by easing lead-times and delivery stipulation;
- Switching to low carbon raw material sources through changes in agriculture sourcing location;
- Optimizing current as-is logistic networks;
- Improving specification of new building and energy consumption in old facilities;
- Packaging elimination, light-weighting and alternative packaging materials;
- Evolving manufacturing process through larger economies of scale in production and switching to low carbon energy source;
- Switching different freight transport modes;
- Importing reverse logistics and recycling activities;
- Near-shoring is both cost-efficient and carbon-friendly new choice.

It seems there already exists plenty of industrial practices in carbon emission reduction in various many manufacturing industries through different stage of supply chain. However, a holistic view or framework to the low carbon supply chain management is still absent and the evaluation system to this carbon-friendly supply chain management is also needed.

3.Case Analysis

Ken Platts (1995) has proposed a framework for analysing and comparison between manufacturing strategy processes formulation. This framework is not only applicable for strategy process but also performance measurement process (Andy Needly, 1995, 2000, 2002, 2006—process-based performance measurement system design), so in analysis to company carbon footprinting process this methodology is applied. In this section, firstly the 4P framework (Point of Entry, Participation, Project Management, Procedure) of Ken's model is introduced; then the multiple cases of different companies are introduced on their carbon footprinting journey, thirdly their PCF activities are framed in by the Ken's model.

4P framework introduction

Platts (1994, 1995) develops a four aspects of process--point of entry, participation, procedure and project management, arguing that a process was not mere procedure--a set of steps, such as the carbon footprinting project.

> "A useful process should specify how an organization might be attracted to implement the process; who should participate in the process and how the project of implementing the process should be managed"
>
> --Platts, 1995

This detailed framework is not only useful to identify the effectiveness and efficiency of process, but also a 'guideline' for good process.

Point of Entry

The 'point of entry' refers to the starting point of the process being introduced into the management system or platform and then being conducted. Platts emphasized that it is necessary for the strategy process to provide a 'method of entry' into the company or business unit and provide a platform to develop the understanding and agreement of the management group. This method of entry should help to: achieving the understanding and agreement of the managing group; establishing the commitment from the managing and operating group; clearly define expectations of what the process involves (Platts,1994). So the way of starting the process should acquire the acknowledgement and commitment from senior group with proper expectation.

Participation

Participation is mapping the individuals and groups that involve in the process. It could include three scopes, the width across different department, depth within the key responsible department (manufacturing in this context), and involvement from outside business, such as consultants, etc..

In the width part, different functions within the company are involved in the process. Platts (1995) believe that other functions have been involved in the strategy process for two main reasons: first for specific activities, such as finance assessing the costs and financial benefits of the options; second, for knowledge that can be brought to the debate and implementation, such as personnel's knowledge of the organization. For the depth of participating, Garvin (1992-manufacturing strategic planning) argued that the depth should be emphasized in order to derive credible, implementable strategy using the best appropriate knowledge in the organization. Participants from outside the business unit generally arrive without assumptions, and with the experience of the process, which is the carbon footprinting in this context.Table 5.1 shows the potential participants categorized by the participation type (Platts, 1995).

Partcipation Type	Composition
Width	Manufacturing, Marketing, Product Development, Finance, involvement of all functions
Depth	People with balance of skills and experience, or political heavyweights
Outside	Corporate specialists, consultants in facilitation/project modes (arriving without assumptions, understand to process, expirienced), facilitator

Table 2 The potential constituents participating the process

Procedure

Procedure of the process includes threefold according to Platts (1995): the first one is an audit to the current process, then the second is the formulation of a set of action plans that designed to close the gaps. The third is to implement the action plans. During the action plan formulation, business process framework might be helpful, but in the lca context, most of the action plans are fixed according to the guidelines. Platts marked that a well defined procedure should progress through through the gathering, analysing information and indentifying opportunities to improvement, which guides the action plan. And easy-to-use tools, techniques and a written record of results at each stage should be included as well.

Project and process management

In Platts's research, two issues in the project management need to be tackled. The first one is the adequate resources for the process, including three aspects: managing, supporting and operating groups. The managing group should secured as backing the process implementation, gaining cooperation across the different functions where the senior management group providing the point of integration. The supporting group performs as the ‘expertise’ in the process, embracing the actions of arrangement, guidance, details-checking. This supporting group most likely would be one person—facilitator—referenced by some researchers. In the carbon footprinting context it is most of the situation and the facilitator acts the most importance role of the process. The operating group comprises the people who are doing the real work: collecting and analysing the data; assessing the requirements of the business, etc. The composition of the operating group may change during the process. The second issue of project management is that a time scale should be set. Platts suggested setting a tight but achievable timescale.

Table 3 4P model of describing process (Adopted from Platts (1995))

	Explaination	Typical Practices
Point of Entry	• Method to achieve the understanding and agreement of the managing group; • Method of establishing commitment from the managing and operating groups; • Clearly defined expectations of aims of what the process involves • Aims: obtain the agreement of the managers to committed involvement in the project	• "Competitive Profiling" • "A tactical to strategic management development programme" raised issues of management style, team membership and a possible workshop(T SWEENEY, 1992) • "Responsibility of board to ensure that a process to make up strategy exists" (Voss) • "New Product introduction" (Leonard-Barton, 1992)
Procedure	• Well defined with clear stages of information gathering, analysing and opportunities identified for improvement • Simple and understandable tools and techniques in use • Written record at each stage • Aims: well defined structure could help operation managers to "see the overall structure of the methodology and appreciate how the individual pieces fitted together"	• A short written report of the process at each stage
Participation	• Individual and group participation team • Workshop style interpretation meetings to collectively agree objectives, identify problems and develop improvements, and to catalyse involvement • A decision making forum leading to action • Aims: generate group working platform across functions team with wide range of opinions and close work between personnel	• Workshop • Decision Making Forum
Project & Process Management	• Adequate resources including managing, supporting and operating group • An agreed timescale	
Adopted from (Platts, 1995)		

Needs to be mentioned, Platts claimed that the process will bring in not only audit to the current operation, but also the delivery of organizational learning (Platts, 1995).

PCF of Case Companies

Total cases pool is shown in the Table 4.

Table 4 Total Cases Pool

Case NO.	Region of firm	Case Name	Involvement	Measurement	Improvement
	US Case				
1		Dell US			
	UK Case				
2		British Sugar			
3		Credit360			
4		Innocent			
5		Sealed Air			
6		Shell			
7		Trucost			
8		NISP			
9		CDP Supply Chain			
	China Mainland Case				
10		Baosteel			
11		Carrefour China			
12		CDP Investor			
13		CNOOC			
14		Dell China			
15		Intertek			
16		Lenovo			
17		Shanghai Auto			
18		Shanghai GM			
19		Tsingdao Beer			
20		WWF			
21		ZTE			
22		galanz			
	Taiwan Case				
23		Acer			
24		TSMC			
25		Donghe Steel			
26		China Steel			
27		AUO			
28		Benq			
29		Zhonglian Resource			
30		ESTC			
31		IRIT			

Since not every case data is sufficient enough for the PCF part, in this chapter we trim the cases pool as following Table 5.

Case NO.	Region of firm	Case Name	Involvement	Measurement	Improvement
F1	Mainland China	Lenovo			
F2	Mainland China	Tsingdao Beer			
F3	Mainland China	ZTE			
F4	Taiwan	Acer			
F5	Taiwan	TSMC			
F6	Taiwan	China Steel			
F7	Taiwan	AUO			
F8	Taiwan	Benq			
F9	Taiwan	Donghe Steel			
F10	Mainland China	galanz			
F11	Taiwan	Zhonglian Resource			
F12	USA	Dell US			
F13	UK	British Sugar			
F14	Mainland China	Baosteel			
F15	Mainland China	CNOOC			
O1	Taiwan	ESTC			
O2	Mainland China	WWF			
O3	Taiwan	IRIT			
O4	UK	Credit360			
O5	UK	Trucost			
O6	Mainland China	Intertek			

Table 5 Cases with PCF process illustrated

4P analysis

In this section the product carbon footprinting processes from case companies are framed by the 4P model for comparison and analysis.		Benq	Lenovo	Tsingdao Beer
Point of Entry	Method of entry into business unit or platform	*The CEO set up the pressure internally for changing the company to a low carbon mode. *a committee of CSR is organized by the General Manager	*CEO of lenovo signed up company internal policy on carbon issue * Requirement from Deutsche Bank of their product carbon footprint report	*The CEO declare the carbon issue management as one of the top priorities of the company--as 'Carbon Asset'. * Its products are exported to UK that is much concerned about the PCF
Participation	Width	Marketing, Product Quality Department, Manufacturing--core departments, Logistics, Finance, R&D--non core departments	Manufacturing, Logistics, Product Design, Public Relationship, R&D (Product Standards and Legislations) departments.	Manufacturing Management, Logistics, purchase
	Depth	A steering team in Product Quality Department. The team members have extensive experience in the product environmental declaration	Under the R&D department, specialists in product environmental regulations and standards	A team of 6 people under the Energy & Carbon Devision of Manufacturing Department is assigned.
	Outside	The Taiwan Government Department of Economic Development set up a consultant project to tutor companies on product carbon footprinting in 2009. 8 consultants from	The primitive measurement is totally internal; the second one targeting China product group Lenovo cooperate with the Energy Research Institute of	A Taiwan Consulting firm--ESTC assist the PCF

		the related Bureau of Industry are sent by the bureau as part of the project.	NRDC. As the pioneering Chinese company coping with product carbon footprint, now Lenovo cooperate with WRI, WBCSD, MIT PAIA program and the CESI in China, setting up the first guidelines of ICT product carbon footprinting in China	
Procedure	Tools and Techniques	Using the eco-LCA software-Simapro, and ecoevent for the source of emission factors. The taiwan EPA provided a template for data collection	Gabi? *And from 2012 using specific tailored internal LCA software from IKE company.	
	Written Record	Set up Benq's own data pool for the continuous improvement	Tracking of carbon footprint of the same product	
	Process Stages	*Supervised by the bureau of industry Taiwan, so the process is following the PAS2050 guidance. *The stages include: Product Identitied; Mapping process and allocate data collection task; Boundary setting of major components; Planning the supplier data collection; data collection for the logistic part; Analysis to the user phrase carbon emission; Analysis to the deposal and recycle phrase CF. *The main bulk of the work comes from the data collection from suppliers(Benq owns very few of manufacturing part). The stage of suppliers data collection include: 1. The first Supplier Meeting for tutorial;2. Collecting data forms and data quality cheking; 3. The second supplier meeting; 4. On-site tutorial for specific suppliers.		

Project & Process Management	Managing Resources	*The General Manager will review the project progress. *CSR committtee headed by the GM	*Setting up CEO(Chief Environmental Officer) from 2006;	* CEO *The head of the manufacturing department * The GMs of Plants are directly responsible for the carbon performance of the plant, and it is the critias along with quality and cost, by which they were assessed
	Supporting Resources	Product Certification Team with the Product quality control centre	Experienced environmental engineer was in charge of the steering team from 2009, titled as Head of low carbon technology and PCF	*Steered by the manufacturing management department, which is the core one in Tsingdao
	Operating Resources	There are project manager in each product lines who assisted the process. Other business unit such as logistics provided data.	Lenovo has built up its internal LCA analysis process and PCF supporting capability. * Tutorial to over 200 suppliers	
	Timescale	*The first product lasts for 9 month, the second product for 6 month, and expected to be 2-3 months after gaining these experience. *The steering team set up a schedule to progress the project forward.	6 months	6 months

Table 6 Cases Analysis in 4P Model

4.Findings

- Supplier Engagement Protocol
  PAS2050 does not mentioned the practical protocol of suppliers engagement, the case data gives out initial framwork:
  Communication Meeting of all suppliers→ First time data collection→ Communication Meetings of all suppliers (Second)→On-site visit to key suppliers 2-3 times

- Difference between developed country and developing country
  Developing country firms focus on streamlined PCF for dealing with the pressure from customer in developed country. Firm in developed country prefer to detailed carbon footprint labeling and get certificated.

- Difference between the assembly-oriented industry and the process-oriented industry
  The PCF of assembly industry focus on the supplier engagement and education, quality from supplier's data is the key issue. For process-oriented industry, data in production process is the key focus. But basic principles applied to both of two.

- Aims different and the validation range could be different?
  This points seems to be revealed in the new PAS2050:2011 Guideline:
  "We have to consider The intended audience for the study. This affects the degree of accuracy and resolution needed. A footprint analysis to be used to identify opportunities for reduction can be undertaken efficiently and at a high level initially, to be built on as needed. For external claims, gaining assurance is best practice, and a rigorous approach to data collection will need to be demonstrated."

- As Tolbert and Zucker (1996) have described a model for the institutionalization process stages: Innovation->Habitualisation->Objectification->Sedimentation. The PCF process follows the model as well.

- The cooperation with a branch institute of external business association could provide firms opportunities to develop structures for LCA activities and monitor/compare their own activities against other organization. ---Which means that business association provides a platform to firms to compare with each other (Baumann,2000). In our cases business association play in an important role.

- In order to influential, the use of LCA have been linked to problem that is generally acknowledged by the company. But the way of proving its usefulness is quite different in industries. Baumann (Introduction and organisation of LCA activities in Industry, 2000) concluded that in Chemistry industry LCA is a means to improve the poor environmental reputation, while the Electronic industry treat LCA as a means to prove the environmental advantages of the industry. In our cases some firms shows the same intentions.

- Some LCA experts (mainly internally) try to develop strategies to make LCA a part of the normal activities in the company. This is the Normalization of green practices.

- In the sedimentation stage, LCA activities have survived across the generalization of organizational members since the idea of LCA has been regarded as granted through the organization. And the organizational structures change emerges, as from the informal LCA teams in the organization to an official LCA committtees/groups and appointment of specialist with specific responsability working towards integrating LCA into general environmental management and business processes.

- In the institutionalization theory, the higher the cost of the investment, the higher of possibility not to lead to abandonment of the LCA practices for the reason to make out of the initial investment.

- If the following LCA studies the results are very similar to each other, a much simplified or IT-supported LCA will be in place, appearing as LCA-based guidelines and indicators. Especially for the large companies, with diverse product groups, the LCA will continuously provide new insight.

- Without the external consultants, the LCA will probably be stopped due to the limited internal knowledge within the organization.(Jensen,2010)
  The standardization process is expected to end with more consistency in the use of secondary data by providing requirements and advice regarding sources to be used.

- As the importance of environmental performance in supply chains increases, it will affect the practice in supply chains.

- With high consistency in secondary data, the focal company would have to prioritize the use of primary data from suppliers to differentiate themselves from competitors.The challenge would be to make suppliers perform better than the secondary data sources and substitute these with more competitive primary data, thereby going beyond compliance with the requirements of the current standards.

- Some researcher argued that the current standards are similar and redundant since the LCA standard already fulfills the purpose of PCF (Weidema,2008 Schmidt,2009), some believes that different standards could co-exist due to the broader focus in LCA compared to PCF, and a more stringent method based on current progress should be encouraged (Jensen,2009; Weidema,2008).

- "An approach for the efficient application of LCA in industry, demonstrated with a case study on wastewater treatment,was the topic of Gerald Rebitzer's presentation. He distinguishes between LCA as a research tool (for policy making, comparative assertions, etc.) and LCA as a management tool (company internal applications with the goal of improving the firm's products). "

- "Gottschick has developed a material flow analysis (MFA) model for the visualization and communication of the aforementioned issues across the process chain. He concluded that this model could support organizational learning that is necessary for the required cooperation of the relevant actors involved."

- "Denis Le Boulch, with his talk on the application of LCA within an international electricity producer, reported on the LCA activities of ELECTRICITY DE FRANCE (EDF), an electricity provider based predominantly on nuclear power. He explained that this form of electricity production shows excellent, results with regard to the impact category 'climate change' (GWP), the results being reported via Internet."

5.Conclusions and future work

This research explores a industrial process to map out holistic profile of carbon footprint of a product and offers a theoretical framework for low carbon emission GSN. This model provides carbon-concerned insight to the designer of GSN, and it builds up supply network reconfiguration and optimization potential in terms of low carbon.

6.Reference

Arena, U., Mastellone, M.L. and Perugini, F.(2003). The environmental performance of alternative solid waste management options: a life cycle assessment study. *Chemical Engineering Journal*, 96, 207–222.

Arntzen, B.C. And Brown, G.G. And Harrison, T.P. And Trafton, L.L.(1995), Global Supply Chain Management at Digital Equipment Corporation, Interfaces, Vol.25, No. 1, Jan-Feb 1995, pp.69-93

Beanmish, P.W. And Killing, J.P. And Lecraw, D.J. And Morrison, A.(1994), International management: Text and Cases, Irwin, USA.

Bellmann, K. and Khare, A. (1999). European response to issues in recycling car plastics. *Technovation*, 19, 721–734.

Blumberg, D.F. (1999). Strategic examination of reverse logistics & repair service requirements, needs, market-size and opportunities. *Journal of Business Logistics*, 20, 141–159.

Boustead, I.H. (1979). *Handbook of Industrial Energy Analysis*. Chichester: Ellis Horwood.

Cairncross, F. (1992). Costing the Earth. Boston, MA: Harvard Business School Press.

Carbon Trust. (2008), "Guide to PAS 2050 – How to assess the carbon footprint of goods and services", in *Carbon Trust.*

Carter, C.R. and Ellram, L.M. (1998). Reverse logistics: a review of the literature and

framework for future investigation. *Journal of Business Logistics*, 19, 85–102.
Caruso, C., Colorni, A. and Paruccini, M.(1993). The regional urban solid waste management system: a modeling approach. *European Journal of Operational Research*, 70, 16–30.
Chopra, S. And Meindl, P. (3rd edition, 2007), Supply chain Management: Strategy, Planning, and Operation, Pearson Prentice Hall, NJ, USA
Chouinard, M., D'Amours, S. and Ait-Kadi, D. (2005). Integration of reverse logistics activities within a supply chain information system. *Computers in Industry*, 56, 105–124.
Cohen, M.A. And Lee, H. (1988), Strategic Analysis of Integrated Production-Distribuion Systems: Models and Methods, Operations Research, Vol.36, No.2, pp. 216-228
Listes, O. and Dekke, R. (2005). A stochastic approach to a case study for product recovery network design. *European Journal of Operational Research*, 160, 268–287.
Louwers, D., Kip, B.J., Peters, E., Souren, F. And Flapper, S.W.P. (1999). A facility location allocation model for reusing carpet materials. *Computers & Industrial Engineering*, 36, 855–869.
Masui, T. (2005). Policy evaluations under environmental constraints using a computable general equilibrium model. *European Journal of Operational Research*, 166, 843–855.
Meixell, M.J. & Gargeya, V.B. (2005), Global supply chain design: A literature review and critique, Transportation Research Part E, Vol.41, pp. 531-550
Mirchandani, P.B. and Francis, R.L. (1989). *Discrete Location Theory*. New York: Wiley.
Min, H., Ko, H.J. and Ko, C.S. (2006). A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns. *Omega*, 34, 56–69.
Mostard, J. and Teunter, R. (2006). The newsboy problem with resalable returns: a single period model and case study. *European Journal of Operational Research*, 169, 81–96.
Mourao, M.C. and Amado, L. (2005). Heuristics method for a mixed capacitated arc routing problem: a refuse collection application. *European Journal of Operational Research*, 160,139–153.
Narasimhan, R. and Mahapatra, S. (2004) Decision models in global supply chain management, Industrial Marketing Management, Vol. 33, Issue 1, pp. 21-27
Nagurney, A. and Cruz, J. And Matsypura, D. (2203), Dynamics of global supply chain supernetworks, Mathematical and Computer Modelling, Vol.37, pp. 963-983
Nagurney, A. and Matsypura, D. (2005), Global supply chain network dynamics with multicriteria decision-making under risk and uncertainty, Transportation Research Part E, Vol. 41, pp. 585-612
Nagurney, A. and Toyasaki, F. (2005). Reverse supply chain management and electronic waste recycling: a multitiered network equilibrium framework for e-cycling. *Transportation Research Part E: Logistics and Transportation Review*, 41, 1–28.
Norek, C.D. And Isbell, M. (2005), The Infrastructure Squeeze on Global Supply Chains, Supply Chain Management Review, Oct 2005, pp. 18-24
Poist, R.F. (2000). Development and implementation of reverse logistics programs.

Transportation Journal, 39, 54.
Prasad, S. And Babbar, S. (2000), International operations management research, Journal of Operations Management, Vol. 18. 209-247
Richter, K. and Dobos, I. (1999). Analysis of the EOQ repair and waste disposal problem with integer setup. *International Journal of Production Economics*, 59, 463–467.
Richter, K. and Weber, J. (2001). The reverse Wagner/Whitin model with variable manufacturing and remanufacturing cost. *International Journal of Production Economics*, 71, 447–456.
Samakovlis, E. (2004). Revaluing the hierarchy of paper recycling. *Energy Economics*, 26,101–122.
Shi, Y. And Gregory, M. (1998), International manufacturing networks - to develop global competitive capabilities, Journal of Operations Mangement, Vol. 16, pp. 195-214
Shi, Y. And Li, R. (2006), An Architecutre Development for International and Inter-firm Networks: From Enterprise Architecture (EA) towards Supply Network Architecture(SNA), 13th International Annual EurOMA Conference: Operation and Global Competitiveness, Glasgow, Scotland, 18th-21st June 2006
Shih, Li-Hsing (2001). Reverse logistics system planning for recycling electrical appliances and computers in Taiwan. *Resources, Conservation and Recycling*, 32, 55–72.
Snow, C.C. And iles, R.E. And Coleman, Jr., H.J. (1992), Managing the 21st Century Network Organizations, Organizational Dynamics, Winter92, Vol.20, Issue 3, pp. 4020
Srivastava, S.K. and Srivastava, R.K. (2005). Profit driven reverse logistics. *International Journal of Business Research*, 4, 53–61.
Richter, K. (1996). The EOQ repair and waste disposal model with variable setup. *European Journal of Operational Research*, 95, 313–324.
Sanchez, L.G., Wenzel, H. and Jorgensen, M.S.(2004). Models for defining LCM, monitoring LCM practice and assessing its feasibility. *Greener Management International*, 45, 9–20.
Stock, J., Speh, T. and Shear, H. (2002). Many happy (product) returns. *Harvard Business Review*, 80, 16–18.
Teunter, R.H. and Vlachos, D. (2002). On the necessity of a disposal option for returned items that can be remanufactured. *International Journal of Production Economics*, 75, 257–266.
Tibben-Lembke, R.S. (2002). Life after death: reverse logistics and the product life cycle. *International Journal of Physical Distribution & Logistics Management*, 32, 223–244.
Warren, J.P., Rhodes, E. and Carter, R. (2001). A total product system concept. *GreenerManagement International*, 35, 89–104.
White, C.D., Masanet, E., Rosen, C.M. and Beckman, S.L. (2003). Product recovery with some byte: an overview of management challenges and environmental consequences in reverse manufacturing for the computer industry. *Journal of Cleaner Production*, 11, 445–458.

Woolridge, A., Morrissey, A. and Phillips, P.S. (2005). The development of strategic and tactical tools, using systems analysis, for waste management in large complex organisations: a case study in UK healthcare waste. *Resources, Conservation and Recycling*, 44, 115–137.
Wu, H.J. and Dunn, S.C. (1995). Environmentally responsible logistics systems. *International Journal of Physical Distribution & Logistics Management*, 25, 20–39.
Yalabik, B., Petruzzi, N.C. and Chhajed, D.(2005). An integrated product returns model with logistics and marketing coordination. *European Journal of Operational Research*, 161, 162–182.
Zhang, H.C., Kuo, T.C., Lu, H. and Huang, S.H. (1997). Environmentally conscious design and manufacturing: a state-of-the-art survey. *Journal of Manufacturing Systems*, 16, 352–371.
Zhu, Q. and Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, 22, 265–289.

The Business Tsunami Effect

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Abstract
In the interconnected networks that have become the dominant life form in today's high-clockspeed industries, companies every now and again suddenly find themselves completely swamped by a flood of operations problems, that seem to be coming out of nowhere. Those patterns can be consumer calls and complaints, order cancellations or even a crisis in the relationship between buyer and supplier. In this paper, it is argued that such apparently unrelated phenomena have many common characteristics, and are indeed different manifestations of what we call a business tsunami, in analogy with the equally rare, sudden and devastating ecological tsunami. Business tsunami are fundamentally different from the much more common bullwhip effects, but are not really utterly unpredictable and totally destructive black "swan events" either. Four real-world examples of four different types of tsunami from 4 different high-clockspeed industries are provided: telecom, electronics, aerospace and ICT. Implications for OM practice and research are discussed.

Keywords: supply networks, high-clockspeed industries, bullwhip effects, black swan effects, operations strategy

1. Introduction
In 2005, former Dutch telecom incumbent KPN took a bold move to fight the competition from the cable companies in the new emerging market of Voice-over-Internet Protocol (VoIP) services, which competed directly with its own traditional telephony services over copper wire. Rather than wait for the competition to eat market share away, it decided to develop and launch its own service. Originally, this new VoIP service was dimensioned for some 500 new customers per week. However, at the end of the first day that the product was commercially available, some 10,000 orders were noted in KPN's order management systems. The new VoIP service proved to be a great commercial success. This success story continued well into the summer of 2006, when champagne was served at one senior management meeting to celebrate the highest monthly number of VoIP sales ever. In retrospect, one can find towards the end of the minutes of that celebrative meeting some mention of concerns about technical issues, about a growing backlog of customers, about capacity constraints, about rising complaints. However, these remained very much outside of

the scope of managerial attention. KPN was busy winning the battle against the cable companies, and one cannot win a battle without making some casualties.

In the autumn, managerial euphoria continued but at the operational levels of the company problems grew and grew, still mostly ignored by senior management. At one point, there was an installed base of some 100,000 customers but also a queue of an equal number of customers to whom the service had been sold but who could not yet use it. For quite a few of those, their previous telephony and internet service had already been disconnected, so customer discomfort was great indeed.

Then, in the winter of 2006-2007, this mounting discontent exploded, right into senior management's face and to their total surprise. A series of consumer programs on national TV was dedicated to the problems with KPN's VoIP service, and in these several members of KPN's top management were grilled by an outraged studio audience and insisting interviewers. In March 2007, a penitent KPN top management publicly announced that for the time being it would stop selling the service altogether, at least until the open issues with the huge backlog of existing customers had been resolved. Eventually, sales recovered but some estimates put the amount of avoidable losses in the first year at some 100 million Euros, and the reputation loss to the once untouchable KPN as both immeasurable and permanent.

Such examples are not at all uncommon in our present-day society. Indeed, one may argue that they are on the rise. Every five or ten years of so, companies especially in our innovation-driven industries are confronted with such a life event, where the build-up of the pressures that are suddenly released with destructive force has remained unnoticed by management, and where the disruptive effects are of such a magnitude that it either kills the companies involved or changes them for good. We call these effects *business tsunami effects*, in analogy with the equally disruptive rare, and hard-to-foresee ecological tsunami, where the pressures that are suddenly released with devastating effects also take a long time to build up, far away from the place of impact, and mostly unobservable.

We will argue that business tsunami are not manifestations of the well-known bullwhip effect (Lee et al. 1997): their impact is orders of magnitude greater, their frequency is much lower, the mechanisms through which they operate are fundamentally different. At the same time, we will argue that business tsunami are not some sort of inherently unpredictable black-swan events (Taleb 2007) either: they occur considerably more frequently than black swans events, they can be foreseen, their development over time can be monitored by tracking not millions but perhaps a few hundred early warning signals and their impact can be mitigated greatly by appropriate organizational designs and policies. If black swans events are 100-1000 year floods, then business tsunami deal with so-called "grey swan events" (Taleb 2007), so resemble perhaps 5-10 year floods. In this analogy, bullwhip effects and wind waves, that keep rolling on all the time.

Our present-day society, where the high-clockspeed supply network has become the dominant life form, appears to be spawning new types of business tsunami continuously. In this paper we present four examples from cases from four different industries of four different types of business tsunami, all equally unexpected and disruptive, but all equally well suited for earlier warning and effect mitigation after appropriate policy redesign. We also argue that the increased prominence of business tsunami must have implications for the research agenda of operations management in general, and certainly for the study of supply chain network dynamics in particular.

2. Ecological tsunami

Frequency
Some 1000 tsunami have been recorded in our history. Not all tsunami are equally disruptive as the 2004 Indian Ocean tsunami or the 2011 Japan tsunami. These happen rarely. But especially if you live in the Pacific "Ring of Fire", which is geologically one the most active fields of the earth, you will encounter a tsunami several times in your life. Japan, for instance, is hit by a tsunami at least once a year (tsunami-alarm-system.com 2013). So, small to medium size tsunami are certainly not once-in-a-lifetime events, especially if you live in an area that is tsunami-prone.

Underlying mechanisms
An ecological tsunami is caused by a sudden vertical displacement of a huge volume of water, usually by a dramatic change in the land at the bottom of the sea, that can travel over water for great distances relatively unnoticed, only to manifest itself with dramatic effects as it hits the sea shore. The reason that the wave remains mostly unnoticed at sea is that there the tsunami wave may have an amplitude of some 3 meters at most and a very long wave length of up to 200 km, travelling at some 800 kilometres per hour. A ship in full sea can easily overlook an increase of some three meters growing in half an hour. However, when the tsunami wave nears the shallow waters near the coast, a process that is called "wave shoaling" (Wikipedia 2013) will compress the wave as is visualised in Figure 1. This decreases its speed to less than 80 kilometres per hour and its wavelength to less than 20 kilometres. This in turn makes its amplitude increase enormously.

Figure 1: Visualisation of amplitude increase as tsunami wave approaches land (Wikipedia 2013)

As mentioned, a tsunami wave is generated by a sudden vertical displacement of the sea floor. This is most often caused by an underseas earthquake, which in turn is generated by the sudden release of pressures between tectonic plates. This is why some 80% of the tsunami known have occurred in the Pacific region, with its high degree of seismicity.

Impact

The impact of tsunami can be massive, both immediately and in the longer turn. The 2004 Indian Ocean Tsunami killed some 230,000 people in 14 countries bordering the Indian Ocean. The 2011 Japan tsunami not only led to some 22,000 deaths but also to a nuclear and humanitarian crisis and had massive economic impact. In addition, there is growing evidence that tsunami can have a major geological long-term effect on the evolution of coastlines. Major tsunami are amongst the most prominent so-called high-magnitude / low magnitude events that influence the morphological evolution of many coastlines (Dawson (1994) and Mastronuzzi et al. (2013).

How big the impact of the tsunami waves is once they hit the shore also greatly depends on the coastal geomorphology. When the waves can move inland without any resistance from the coast, for instance in a lagoon, the impact is much greater than when the wave encounters mangroves or even forests. In geology, a formula has been derived empirically that estimates the maximum flooding distance for a certain wave length depending on the height of the tsunami wave as it hits the coast line:

$$Xmax = \frac{HT^{1.33}}{n^2}k$$

Here *Xmax* is the maximum flooding distance, *HT* the height of the tsunami wave, k the so-called tsunami constant of 0.06 and *n* the so-called Manning number (Manning 1891). Different empirically derived values for this Manning number are listed in Table 1.

Table 1: Different coastal types an appropriate Manning number for mitigation of tsunami impact

Coastal Types	Manning number (100*n)
Lagoon, fluvial plain	1-1.5
Mediterranean vegetation	1.6-2.5
Farm area	2.6-3.5
Discontinued dune belts without vegetation	3.6-4.0
Dune belts	4.1-4.6
Rocky coasts	4.7-5.2
Urban area discontinuous	5.3-5.8
Urban area with concentrated buildings	5.9-6.4
Mangroves	6.5-6.9
Forests, pinewoods	>7.5

So far for ecological tsunami and the state of the art in geology in understanding what causes tsunami and what may mitigate their effects. Now, we move to the business world. Would we there eventually also be capable of determining a “Manning number” for business tsunami?

3. Business tsunami

When we compare what we mean by business tsunami with the established notion of ecological tsunami, then the number of similarities is striking. Both types of tsunami:

- Happen rarely, but in some tsunami-prone environments once-twice every decade;
- Occur suddenly, apparently out of nothing, and have their origin in some distant location;
- Are hard to observe before they reach their "impact zone";
- Result from a sudden release of long-building pressures;
- Have some advance predictability but within longer time horizon;
- Have, once they have occurred, only short advance warning signals;
- Have disruptive effects in their impact zone;
- Can have their effects mitigated or aggravated, depending on the morphology of the impact zone;
- Can have a major long-term formative impact on the structure of their impact zone;
- Lead, over time, in environments that are tsunami-prone, to a tsunami mindset, a mentality that is conducive to watching out for high-impact/low likelihood events.

An emerging typology of business tsunami

Our present-day society, where the high-clockspeed supply network has become the dominant life form, appears to be spawning new types of business tsunami continuously. In this paper we present four examples from cases from four different industries of four different types of business tsunami, all equally unexpected and disruptive, but all equally well suited for earlier warning and effect mitigation after appropriate policy redesign. A brief overview of these four is presented in Table 2.

We have selected these four cases because they are suitable examples of these types of tsunami and because they are well-documented in the publicly available literature. Moreover, in three out of four of these types of tsunami cases, one of the authors has been directly involved as action researcher.

Name	Likely candidate area	Mechanism	Example
Quality cascade tsunami	IT-enabled service supply chains (telecom, banking, public services)	While new orders keep coming in, rework and delays are piling up, leading to customer discontent which eventually erupts	Telecom, KPN 2006-7 VoIP service introduction
Demand bubble tsunami	Machine tools, production equipment for high-tech electronics	Due to capacity constraints with equipment suppliers and fast-rising demand from final customers, customers order ahead and double with equipment suppliers, until they find that true demands have been met	Electronics Machine equipment, CISCO 2001 Dotcom bubble and Semiconductor 2008 Credit Crisis
Schedule pressure tsunami	Complex New Product Development projects	Overoptimistic delivery schedules lead to an accumulation of quality issues, which suddenly surface	Aerospace new aircraft development: Airbus A380 2000-2006, also Boeing Dreamliner, F-35
Relationships spiral tsunami	Captive buyer-supplier relationships, outsourcing	An initially cost-driven outsourcing deal leads to asset-sweating supplier, deteriorating service quality and increasingly dissatisfied customer, which eventually leads to an outburst	IT Outsourcing in Telecom, KPN-Atos Origin outsourcing deal 2001-2003

Table 2: An emerging typology of business tsunami

4. Case 1: Quality Cascade Tsunami in Telecom

Case synopsis

KPN is in the Netherlands the privatised offspring from the former state-owned national post, telegraph and telephony utility. Back in 2005, it was the leading telecom service provider in the Netherlands. In its home market is suffered from strong competition from the cable companies, who originally provided only TV signal transmission, but had successfully begun to offer broadband Internet access and were moving to telephony over the Internet, so-called Voice over Internet Protocol (VoIP) services. In a bold move, KPN top management decided in May 2005 that it would attack the cable companies with its own VoIP service, even if this would mean cannibalizing its own conventional telephony services over copper wire (Computable 2005). Initially, this move was a great commercial success. As explained in the introduction, the numbers of customers that were interested in this service was much greater than was anticipated, and also much greater than the company's internal service supply chain could handle. Little by little, unobserved by most and certainly by top management, quality issues accumulated and so did the queue of customers waiting to have their VoIP service established properly. Figure 2 show the massive peak in sales in the second half of 2006.

Figure 2: Normalized weekly sales of VoIP service, 2006-2008 (Source: KPN)

Figure 2 also shows the massive drop in sales at the end of Q1 of 2007, after a public outrage of very dissatisfied customers (TROS RADAR, 2006a and 2006b) in September-December 2006 had led to a public whipping of KPN on national TV. In February 2005, KPN top management felt it had no other option than to stop promoting the service altogether (Tweakers.net 2007), at least until the existing overfilled pipeline of customers who had bought the service but could not yet benefit from it had been emptied. As Figure 2 suggests, sales did recover eventually but conservative estimates put the avoidable costs made to recover from this tsunami at over 100 million Euro (Computable 2007).

Underlying mechanisms

What led to this tsunami of complaints and public attention and humiliation for KPN, and, even more importantly, to so much distress and discomfort for tens of thousands of customers? Figure 3 summarizes our synthesis of a series of workshops with KPN staff at that time as well as of related studies on service supply chain dynamics (Akkermans and Vos 2003, Akkermans and Voss 2013). It shows a series of reinforcing feedback loops, all leading to an ever-increasing pressure on the system.

Our explanation starts with the notion that the inflow to the backlog of work, which is called work in progress here, is much greater than the outflow. The inflow comes from the sales of new services, and this is shown in Figure 2. The outflow is determined by the capability of the service supply chain in dealing with this inflow. This capability was much lower than the processing capacity required. This led to higher workloads, and higher workloads inevitably lead to more errors (Oliva and Sterman 2001). This leads to rework, and that not only further increases the work backlog (work has to be done twice), but also limits order processing further. One result of this very high work pressure was unhappy staff (loop R2), and when these walk out in greater numbers than normal (annual attrition rate in KPN's call centers at this time was well over 100%), then this further decreases the order processing capacity available. Over time, more and more people were hired to do the work that was really needed, at one time some five times more than was originally expected to be required (Computable 2007a). But hiring these and training them takes time (loop

B2). In the meanwhile, customers become extremely dissatisfied, fed up and leave (loop B1) or file complaints. Both require additional capacity to handle. In the end, the only solution is to drastically reduce the inflow, when the pressure has become to high, and this is precisely what happened. This case is a real-world example of what we call a quality cascade tsunami: quality issues cascade down the service supply chain from order handling to the call center to the complaints department, requiring capacity to handle them at every stage (Akkermans and Vos 2003).

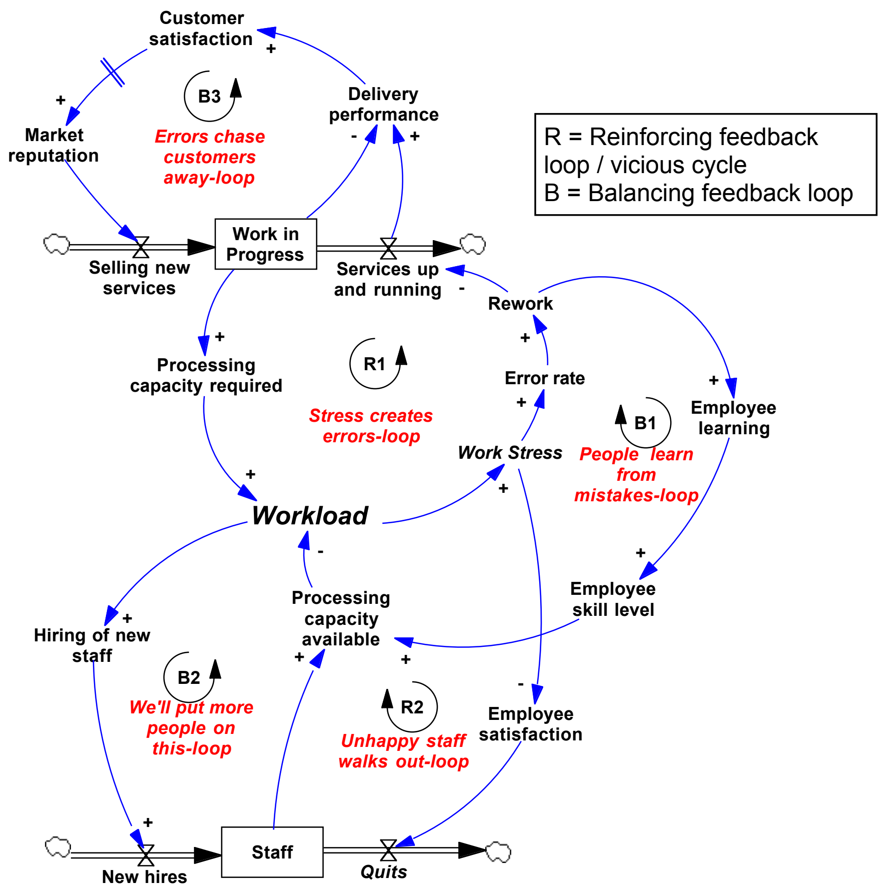


Figure 3: Feedback loops describing the vicious cycles that may create a quality cascade tsunami of major quality issues and a huge backlog of waiting customers

Lessons learned

Ramping up IT enabled service successfully is indeed a complex undertaking, and it has taken KPN and its competitors several years to learn how to do it well. The key is not to let the backlog of new customers become too large, as this will trigger a number of tipping points as shown in Figure 3. That can be done by either not scaling up sales too fast of by making sure that there is sufficient capacity available to deplete the backlog Apparently, the company has learned how to do this really well by now, as Figure 4 suggests, which is the ramp-up of another service from KPN from 2010 onwards. Never has the order backlog here been higher than more than 2 or 3 weeks leadtime.

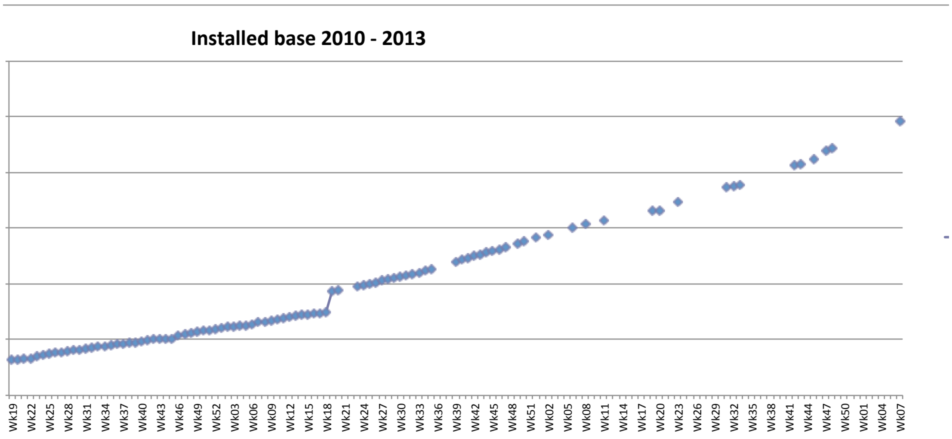


Figure 4: Installed base development of another KPN service, 2010-2013

5. Case 2: Demand Bubble Tsunami in High-tech equipment

Case synopsis

Around the start of the new millennium, it appeared that the economy was in a permanent state of euphoria. Stock markets reached record heights, the economy kept growing, life was good. Especially in the high-tech sector, this was the best-ever time for many. The combined rise of high-speed internet and mobile communication led to wonderful prospects for all companies active in these innovation-driven industries. One such company was CISCO, back then the world-leader in the manufacturing of computer networks equipment. In 1999, 80 percent of the routers connected to the Internet were Cisco machines. From 1995 onward, CISCO had been growing fast, both from organic growth and from a series of acquisitions. Throughout this period, it had kept beating expectations of the financial analysts (NYT 1999, 2000). Briefly, it was the world's most valuable company. At one point in March 2000, its market capitalization reached a peak of $560 billion, more than those of General Motors, Citigroup and Wal-Mart combined. The second quarter of 2000 was its 42 consecutive quarter of revenue growth (NYT 2000) and its stock price reflected this, as Figure 5 illustrates.

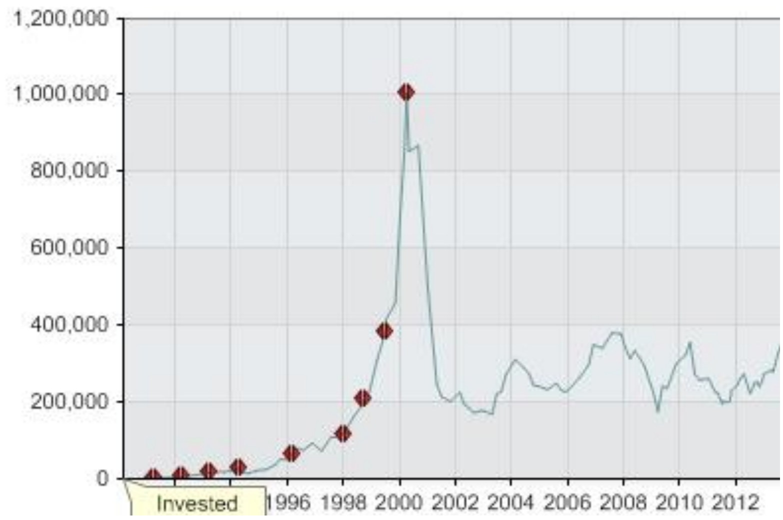


Figure 5: Development over time of the value of CISCO stock, 1995-2012

What could explain this spending spree by CISCO's customers? ? According to CISCO's CEO John Chambers, it was because the world had changed for good:

"Globally, business and government leaders are beginning to dramatically transform their traditional business models into Internet economy business models. Business leaders are beginning to get it, and as they get it they begin to bring the applications up and spend at an accelerated rate." (NYT 2000).

Apparently, the "old rules" of the "old economy" no longer applied. Unfortunately, that has for centuries been the story during a demand bubble (Reinhart and Rogoff 2011), and this turned out to be the case here as well. In a rush to meet the challenges from these "Internet economy business models", all CISCO's customers had been ordering equipment aggressively, often ordering ahead and even placing double orders, in response to anticipated shortages and delivery delays. CISCO itself, in order to secure timely delivery of these orders, had decided to place fixed orders in its supply base. But when the economy cooled down, customers found out that they really didn't need all these routers they had ordered earlier on, and started to cancel orders or push them out in the future. As a result, CISCO's order book declined rapidly, and it was faced with large amounts of excess stock.

This became apparent to the outside world in February 2001, when, CISCO announced for the first time in 11 years that it expected revenues to decline (NYT 2001a). The company said that for accounting purposes it would reduce the value of inventory by $2.5 billion this quarter, including $500 million in partly completed equipment and $2 billion of raw materials like computer chips (NYT 2001b). The inflated demand bubble had finally burst. In a conference call in April 2001, Mr. Chambers put what happened outside of his own responsibility, stating that the economic challenges confronting the network equipment industry are proof that "a 100-year flood can happen in your lifetime." (NYT 2001c).

Underlying mechanisms

The underlying dynamics of demand-bubbles generated by capacity shortages have been studied and analysed rigorously with system dynamics modelling by Gonçalves (Gonçalves 2003). Figure 6 shows the causal loops that describe the mechanism through which such a demand bubble can be generated based on this work. One reinforcing loop (loop R1) suffices to create a demand bubble. Customers who notice that there is a capacity shortage with the OEM, which makes their leadtimes go up, will start ordering ahead to assure that their supply line is filled adequately. If leadtimes are doubling, they need twice the order backlog to assure the same shipment rate, according to Little's Law (Little 1961). What closes the loop is that, as backlog increases, leadtime will increase even further, prompting customers to order ahead even further, thereby increasing backlog even more, etcetera. Of course, the OEM tries to increase capacity as quickly as possible (loop B1), but equipment supply chain delays are notoriously long and one simply cannot keep up with a demand bubble.

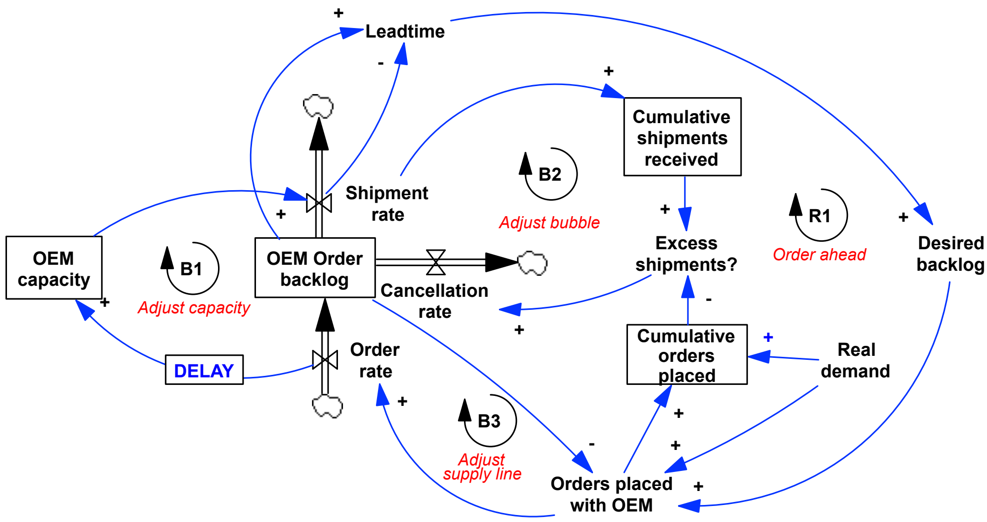


Figure 6: Causal loops describing the vicious cycles that may create a demand bubble tsunami during capacity shortages (based upon Gonçalves 2003)

All this continues until the bubble bursts. In this model, that tipping point occurs when customer realize that the real demand that they have accumulated over time has by now been fully met by the shipments from the OEM. Obviously, the OEM's backlog is still filled with inflated orders. These inflated orders are then suddenly cancelled (loop B2), and the new order rate drops to a very low level (loop B3). As a result, the remaining orders can be fulfilled quickly, which leads to a drop in the leadtime, and this shorter leadtime then implies a much smaller supply line. All this can happen in a very short time frame, as it did towards the end of 2000. Many high-tech equipment suppliers were left with huge obsolete inventories and substantial excess capacity. This is how a demand bubble tsunami operates.

Lessons learned

As indicated, the entire high-tech industry, certainly the telecom and electronics industries, suffered under this tsunami in 2000. Fortunately, most of the sector also learned from it. After all, this was by no means a 100-Year-Flood outside of managerial control. Eight years later, in 2008, when the credit crisis hit, the electronics sector was affected even worse than in 2000. However, electronics manufacturers, electronics component manufacturers, and even electronics production equipment manufacturers, bounced back within a year, mainly because everybody had been keeping much closer track of both underlying demand and inventory positions. When semiconductor demand peaked again in 2010, Intel CFO Stacy Smith observed that customers and manufacturers alike were keeping a key eye on supply and demand: "When we look through the supply chain, what we see are healthy and appropriate inventory levels relative to how we see demand" (Business Week 2010).

6. Case 3: Schedule Pressure Tsunami in Aerospace

Case synopsis

In the market segment for large wide-body passenger planes, it has long been Airbus against Boeing. In 2001, Airbus placed a strategic move in this battle of the giants with the announcement of the development of the A380, which would displace Boeing's 747-400 as the world's biggest commercial jetliner. In January 2001, Airbus announced that it had enough orders to begin the A380's production and that is planned to fly a prototype in late 2004 (NYT 2001d). But that would prove to be overly optimistic, to say the least. The root causes were (a) "super-size technical challenges" (NYT 2006a), (b) an almost equally complicated organizational structure that had to deliver that design and (c) an over-ambitious overall time schedule. Looking back on the project in 2006, one Airbus union official observed: "Normally you need four to five years from the time you announce the launch of a new plane until delivery (..) Airbus had never built a plane of this complexity before, and yet managers did not take the precaution of building more flexibility into the delivery schedule." (NYT 2006a).

In 2004, the issues in design, that can be traced back to a usage of different Computer Aided Design tools by different parts of Airbus, had led to a situation where engineers in Hamburg were falling behind schedule and fuselage sections that were supposed to be shipped "prestuffed" with their electrical cables arrived with half or less of the required wiring. (NYT 2006). Wiring in the A380 may not have been the first technical challenge one might think of, but in the end it were humble wiring problems that proved lethal to the project, which is perhaps not so surprising with some 300 miles of cable in one plane.

The design issues led to delays but these delays were for a long time ignored: "Throughout the autumn of 2004, assembly line managers duly reported the problems at the plane's regular progress review meetings. But no one, at that stage, seemed to believe they were significant enough to merit a red flag to top management" (NYT 2006a). So, the outside world remained ignorant of the production delays. For this outside world, the delivery schedule remained unchanged, and airlines continued to plan their future flight operations based on that delivery schedule.

In 2005 the situation got worse: "The cost overruns and delays to the superjumbo project were raised at a May 12 meeting of the EADS board convened to certify the company's financial results for the first quarter, which were due to be published the following week. Minutes from that meeting show that "several board members (…) questioned whether the delays were significant enough to merit a warning to investors. (…) The board held off — another delay in getting material information to shareholders." (NYT 2006a). However, one month later company executives could no longer stay in denial and made their first public admission of manufacturing troubles in which they announced a six-month delay in the plane's delivery schedule (NYT 2006b).

The first announcement in 2005 was followed by another delay announcement in 2006. The impact of this second wave of bad news was massive. Not only did Airbus's parent company instantly loss some 7 billion in market value (NYT 2006b), and did the top officials of both EADS and Airbus step down (NYT 2006c), but after yet another delay in October (NYT 2006d) customers started to actually cancel orders (NYT 2006e). In March 2007, EADS, Airbus's parent company, had to report its first-ever loss of 3.3 billion Euro (NYT 2007b), and had to fire some 10,000 employees in its manufacturing facilities (NYT 2007a).

Underlying mechanisms
What went wrong? Here we borrow from the analysis made by van Oorschot et al. (2013) of a new product development program in the semiconductor industry that also faced major delays due to accumulating quality issues. In the semiconductor example, shortly after the bubble burst and the delays became public, the entire project was cancelled. This did not happen to the A380, but apart from that, the saga of the Airbus A380's development and market introduction looks remarkably similar. Figure 7, which also appears in Van Oorschot et al. (2013), shows the main feedback loops that may generate a schedule pressure tsunami.

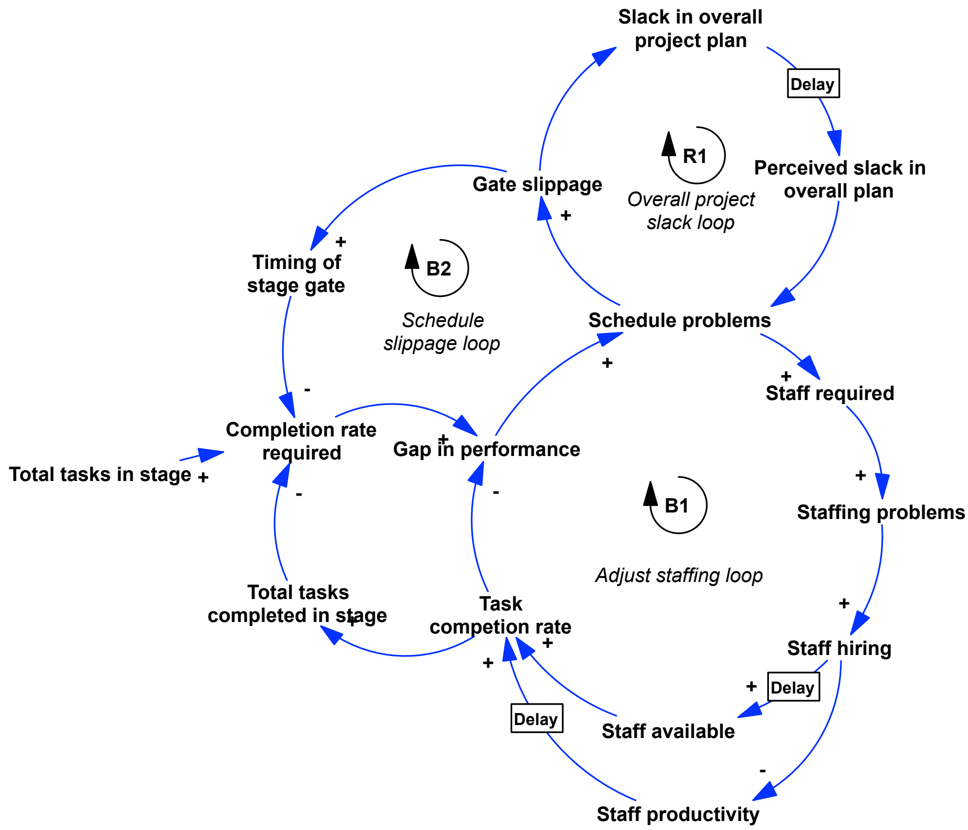


Figure 7: Causal loops leading to vicious cycles that may create a schedule pressure tsunami without project slack and with many quality issues remaining (van Oorschot et al. 2013)

We start with loop R1, where we note that several of the executives interviewed about the A380 case have indicated that from the beginning, there was both an ambitious timing of the various project gates as well as little slack in the overall plan. As loop R1 shows, it takes time to get over the denial phase and reduce the slack in the overall project plan. For a long time, delaying the overall project end date remained the road not taken. What did happen was the process shown in loop B1, hiring more staff and hoping that they will generate the productivity increases that were required. In product development "Brooke's Law" still reigns, which says that adding engineers to a design project in trouble will delay it only further (Abdel-Hamid and Madnick 1991). So, at best these capacity increases led to a higher task completion rate over considerable time.

Meanwhile, the gap in performance keeps growing, which only further increases schedule problems. One short-term fix to deal with schedule problems is loop B2, which visualises that one can delay the current project phase without readjusting the overall schedule. This clearly happened as well. The result was, in the words of the Airbus manager in charge of the programme late 2006: "We ended up with a vicious circle where there was apparently no way out," (NYT 2006a). In the end, there was no slack left and the tsunami of bad news travelled to the world outside world, with the before-mentioned disastrous effects on customer and investor confidence and on the financial and employment results for EADS.

Lessons learned
It remains to be seen if the aerospace world, or the world of big complex projects in general, has really learned from this experience. Both the Boeing 787 and the Lockheed Martin F-35, the two other major new aircraft development projects of the previous decade, have seen major quality issues, delays and project overruns. Perhaps, in the way that it is setting up the programme, it may be that Airbus itself has learned some lessons of realistic schedule setting with its most recent A350 programme. Although, this most recent programme again has been delayed with some months so far, according to Airbus because the "transition phase from design to manufacturing is a bit longer."…. (Flightglobal 2010).

7. Case 4: Relationship Spiral Tsunami in Telecom

As in our personal lives, relational issues are quite common in business as well, but for the biggest part they remain carefully hidden. No party really has much to benefit from having its fight with a key supplier or customer exposed to the scrutiny and judgment of the outside world. Nevertheless, relational conflicts in buyer-supplier relationships are very real and they too can generate a business tsunami. A relationship spiral tsunami occurs when a buyer and supplier become caught in a so-called relationship spiral (Autry and Golicic 2010) of every-growing distrust, opportunistic behaviour and poor operational performance on both sides of the relation.

Case synopsis
The burst of the dotcom bubble in 2001 did not just hurt CISCO and many other high-tech equipment makers, it also brought the telecom sector to its knees. The same company KPN from the quality cascade tsunami case lost 90% of its stock value in June 2001 (Computable 2001a) and had to fire some 4,800 staff (Computable 2001b). It faced huge debts and was in dire need of cash. KPN top management decided to outsource most of its IT activities to the highest bidder. The lucky winner of this bidding contest was the French-Dutch IT company Atos Origin, that took over the bulk of KPN's IT activities between July 2001 and August 2002 (Computable 2002a and 2002b), together with a 5 year revenue guarantee from KPN. Soon however it became apparent that Atos was not the lucky winner of this deal, this win also came with a curse, the co-called "Winner's Curse" in IT outsourcing (Kern et al. 2001). Managing KPN's IT turned out to cost more than anticipated, and the revenues from this deal turned out to decline much faster than anticipated, due to a further decline of the telecom business.

In 2002-2003, the relationship between Atos and KPN deteriorated more and more. Virtually all of these issues remained outside of the public press, but the main case outline is presented in a conference paper by Akkermans and van Oppen (2006). In here, one can read the following reasons for this deterioration: The original set-up of the outsourcing deal was working against improved performance and partnership. KPN continued to look for cost-cutting opportunities to regain profitability. This led to lower than expected IT expenditures. This, however, invoked penalties under the Revenue Guarantees that had been agreed upon for 5 year. To counter these, KPN occasionally would enter into ill-founded projects with Atos not for competence-based reasons, but mainly financial ones, i.e. only to avoid penalty costs. This situation was aggravated because at KPN IT in-sourcing capabilities had been out-sourced, and supplier relationship management remained under-developed and shaky.

What also turned out to be counter-productive is that the cost-down drive at KPN was directed at the business units of KPN, whereas the original outsourcing deal had been a corporate one. As a result, KPN business units felt it was unfair that they had to solve a problem (revenue guarantees and associated penalties) that was not caused by them. On the other side, the revenue guarantee inevitably led to complacency at AO. This business set-up gave Atos the incentive to utilize its current assets as much as possible and not spend energy on developing major innovative, cost cutting ideas. Atos was perceived by KPN as to be “leaning against the fence” and not to be the risk-taking innovative partner that KPN was eagerly looking for on its way back to business prosperity (Akkermans and van Oppen 2006).

Over the course of 2003, operational quality deteriorated below tolerable levels, as a result of the poor collaboration between the two companies. There were dozens of outages in the IT infrastructure, and the complaint percentage of even the most conventional telephony services was unacceptably high. Customer satisfaction with KPN management for the services rendered by Atos dropped to around 4 on a scale of 10. What started as a financial issue had now really begun to hurt the operational service that KPN’s final customers experienced.

These growing pressures were released on October 29, 2003, when, at the three-monthly Partner Board Meeting between top management of KPN and Atos, KPN’s CFO delivered a message to Atos intended to redefine the relationship. This message was that KPN was very dissatisfied with the way things were going so far, realised that the manner in which their joint relationship was defined lay at the root of the current performance and proposed to redefine this relation drastically. The choice for Atos was clear: either go along with this proposal, or run the risk that KPN would make its’ dissatisfaction public (Akkermans and van Oppen 2006).

Fortunately, this crisis could be reversed into a productive relation in the ensuring years, albeit at much lower levels of activity. Also, KPN would insource large parts of its IT capabilities, such as its data centres, some years later on (Computable 2007b). However, these reconstruction activities after the relationship spiral tsunami had hid fall outside of our current scape.

Underlying mechanisms

The relationship spiral tsunami that played out between Atos and KPN resembles greatly the relationship spiral tsunami between two product divisions from Philips Electronics, the Semiconductor and the Component division, who went through a similar relationship roller-coaster in the 1999-2002 period. This case has been described and analysed in Akkermans et al. (2004), and the summarising causal loop diagram from that case is reproduced in Figure 8.

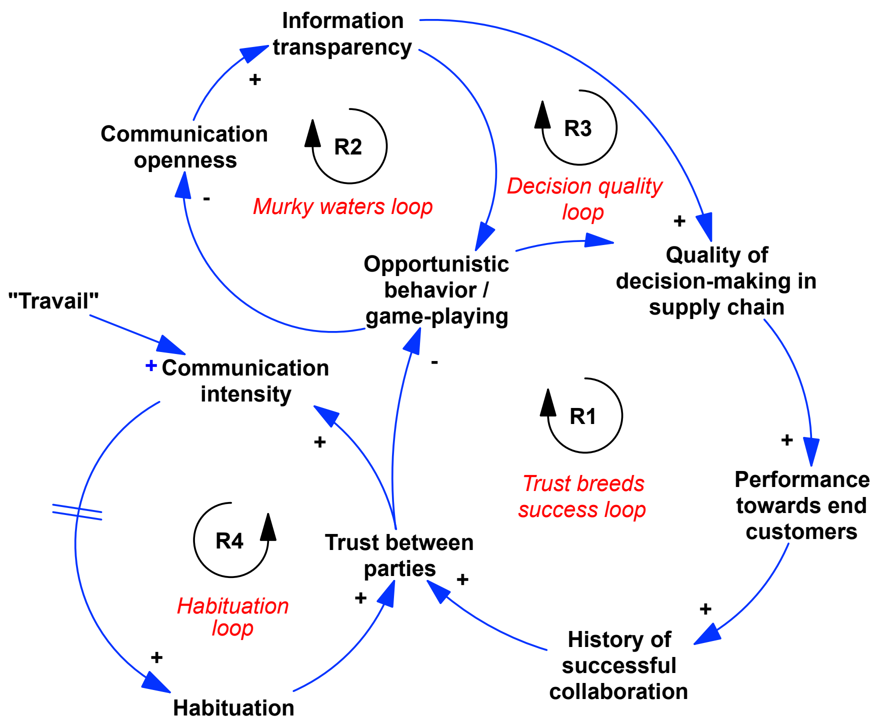


Figure 8: Causal loops that generate the vicious cycles that may lead to a relationship spiral tsunami (Akkermans et al. 2004)

Figure 8 shows four reinforcing feedback loops, R1 to R4. The other kind of feedback loop, the balancing (B) feedback loop, is goal-seeking: by nature it seeks control, equilibrium, stability. Reinforcing feedback loops are by nature de-stabilizing. This means that when the variables in them grow stronger, they will grow stronger still. When they become smaller, they will become smaller still, all other things considered even. This diagram has four destabilising loops, one can imagine the outcome.

R1 is the trust-breeds success loop. This loop can generate both a vicious and a virtuous cycle. In the case of a relationship spiral tsunami, it is the vicious cycle that becomes active. As parties trust each other less, they will entertain more in opportunistic behaviour, in game-playing. This will lead to a deterioration of the quality of decisions made, since these decisions will be based on incorrect and incomplete information and on biased goals. This will hurt the joint performance towards end customers and this will lead to a track record of unsuccessful collaboration. This will hurt trust on both sides even more.

More opportunistic behaviour leads to less information being shared. This feeds into loop R2. The less transparent a business setting is, the more opportunities there are for cheating. This is why we call this loop the murky-waters-loop, in recognition of the saying “fishing in murky waters”. Moreover, with less information available for decision-makers, their decision-making quality will deteriorate. This is loop R3. How can this situation be reversed? What was tried successfully in the Philips case, and what was tried successfully once more in the KPN-Atos case, is the notion of “Travail”, of bringing all the relevant parties in the same room and develop jointly a detailed picture of how the relevant operational processes interact. This leads to better insights but also to a period of intense communication. Intense communication leads to habituation, and habituation breeds trust (Nooteboom 1996).

Lessons learned

At present, the authors see little evidence their either the companies involved in this particular case, or companies in general, have learned much from this particular instance of a relationship spiral tsunami, nor from relationship spiral tsunami in general. Apparently, this type of business tsunami will be with us for some time still.

8. Discussion

In this paper we have introduced a new phenomenon. But is it really new? Is it not rather an example of some OM phenomenon we already know? This is a valid question, and so we will first discuss why business tsunami are indeed fundamentally different from the better-known phenomena of the bullwhip effect (Lee et al. 2007) and the black swan event (Taleb 2007).

Business tsunami are different from the bullwhip effect

There are some similarities between a "normal" wind wave and a tsunami wave, but it is simply not helpful to suggest that a tsunami wave is a special case of a normal sea wave. Yes, they are both waves that travel to the shore and both are subject to wave shoaling and yes, people get killed by wind waves as well, but the differences are large enough to treat them as fundamentally different phenomena. A normal sea wave at sea is some 100 meters, not 1-200 kilometers. Wind waves occur continuously, in every part of the world, while tsunami waves occur only every 1-10 years, and in specific environments only. Wind waves are caused by the wind and gravitational forces, tsunami waves are caused my underseas earthquakes which are generated by tectonic plate movements. And so the list could continue.

In a similar fashion, there are similarities between the bullwhip effect and the business tsunami effect, but it is simply not helpful to suggest that the one is a special case of the other.

Table 3: Differences between bullwhips, business tsunami and black swans.

Dimension	Bullwhip Effect	Business Tsunami Effect	Black Swan Effect
Magnitude	X	10-100X	100-1000X
Structural impact	Little	Significant	Very great
Frequency	Every year	Every decade	Every century
Number of likely causes	Well known, <20	Reasonably known, <200	Inherently unknowable, >1,000,000
Managerial focus	Constantly (and must be)	Rarely (but should be)	Never (and can't be)
Underlying mechanism	Demand signalling, order batching, price fluctuations, shortage gaming	Slowly-building non-observed pressures, suddenly released at tipping point	Combination of multiple very unlikely events with massive impact
Foreseeable	Yes, precise timing and magnitude no	Somewhat, not in timing and magnitude	Utterly unforeseeable
Mitigation possible	By policy adjustments	By structural adjustments	By cultural adjustments

Table 3 summarizes the main differences between the bullwhip effect and business tsunami effects. First, there is their *magnitude*. We associate with the bullwhip effect an amplification factor (Sterman 2000) of say 2, which means that a 10% demand increase in one echelon leads to a 20% increase in the next echelon upstream. However, business tsunami typically have an amplification factor of a manifold of the original value, rather a factor of 10 to 20 if not more. Then there is their *structural* impact. Companies are affected by the bullwhip effect, but rarely so that their businesses change fundamentally. With the business tsunami effect, a structural change in the way the business is operated is rather the rule than the exception after the tsunami has hit home.

Next there is *frequency*. Bullwhip effects occur just about every year, certainly in cyclical industry with a cycle of some 3-5 years. Bullwhip effects are always around us. A practicing manager will during her career of some decades most likely experience several business tsunami, unfortunately often of different kinds and with such time spans between them that their lessons are hard to make and easily forgotten (Sengupta et al. 2008).

What causes bullwhip effects in a given industry is well known in most cases. In some settings it is the cyclicality of the downstream supply chain, in other settings it is simply the order-up-to effect from ERP systems (c.f. Hopp & Spearman 2000). So, the *number* of early warning indicators that management has to monitor is just a handful "usual suspects". Business tsunami are caused by what Taleb (2007) calls "grey swans". These are not extremely unlikely events, but still fairly unlikely events. Their likely early warning indicators number hundreds, which is still doable to monitor, but a lot more work than needed to track the bullwhip effect.

Because of their low frequency and the many possible triggers for them, it is not so surprising that management rarely is on the lookout for business tsunami. Indeed, there is a real risk of a Maginot Line syndrome, of generals trying to win the first war (The Maginot line was an advanced line of defence between France and Germany, built by the French army after the 1st world war, which the Germans easily circumvented in WWII by moving their tanks via neighbouring Belgium and Holland during their "Blitz-Krieg".)

The underlying *mechanisms* for the bullwhip effect are well known and have been described by Lee et al. (2007): demand signalling, order batching, price fluctuations, shortage gaming. Forrester (1961) saw as a common underlying cause the delays and feedbacks in decision-making in supply chains, and Akkermans and Voss (2013) have noted that these four mechanisms operate differently in service supply chains, as opposed to manufacturing supply chains, but all in all we know what we are dealing with. In this paper, we suggest a common underlying mechanism for business tsunami as well: Slowly-building non-observed pressures, suddenly released at a certain tipping point. However, the bullwhip effect is much, much better researched with dozens if not hundreds of papers dealing with it. At any rate, it is clear that the underlying mechanism is very different from the bullwhip effect, although there are of course also some similarities.

By now, after over 50 years of research and practical experience with it, we argue that the bullwhip effect is quite *foreseeable*. For business tsunami, this is much less the case. There is the much larger set of indicators the watch, there is the limited set of theory on how tsunami "work", there is the much longer time horizon between one tsunami occurrence and the rest, and there is the emerging typology of different kinds of typology. So, in principle, business tsunami are somewhat foreseeable, but in practice the vast majority of companies clearly still finds this very difficult to do. There is still much work to be done, hopefully not the half-century of work that was needed to make the bullwhip effect a household phenomenon.

A similar distinction can be made for the *possibility of mitigating* bullwhip effects versus business tsunami effects. The fact that may industries and companies are still suffering from the bullwhip effect does not mean that these effects cannot be mitigated, provided the appropriate measures are taken. Mitigating the effects of business tsunami will be much more difficult, for all the reasons mentioned above: their impact is much greater and therefore harder to diminish, their frequency is much lower and therefore it is more problematic to keep focus. We know much less about the mechanisms behind business tsunami so it is less clear how they can be best mitigated. All this is work to be done in the coming years and decades, and this paper hopes to make a modest first contribution to this work.

Business tsunami are no "Black Swans"

Neither are business tsunami black swan events, in the sense that Taleb (2007) has defined them. At best, they rank as "grey swan" events: fairly unlikely and fairly rare, but not extremely so. Again, a comparison with the ecological tsunami may be illustrative. There have been some mega-tsunami in the past: The extinction of the dinosaurs has been attributed to the "Chicxulub impactor" (Wikipedia 2013b), a massive comet/asteroid impact some 66 years ago, somewhere for the coast of Yucatan, which wiped out some 75% of all life on our planet. Now there is a black swan event. Or, on a lesser scale, and again leading to a massive tsunami, but immensely destructive nonetheless, the Santorini eruption of 1610 B.C., which may have inspired Plato's story of the destruction of Atlantis and certainly led to a major tsunami and the formation of the present-day Santorini caldera (Wikipedia 2013c).

These are true black swan events, events that happen not every few years, but every millennium, and that do not result from gradual tectonic plate movement, but from a sudden destructive force coming out of nowhere. Their destructiveness is also of an altogether different scale. The vast majority of the thousand recorded tsunami are just altogether different beasts.

Table 3 also contrasts business tsunami with black swan events. Business tsunami happen every 5-10 years, but black swans happen much rarer, perhaps just every century, let's say the Great Depression, or WWII. Their impact is also much more destructive. Black swans events can completely wipe out industries, so their structural impact is also much greater. They can come from anywhere. This also means that there is little point in looking out for them, they can't be on the managerial dashboard because they cannot be foreseen. What companies can do is be sufficiently agile to deal with crazy events, to have a "triple-A supply chain" (Lee 2003). This requires more than process and organisational adjustments, but even cultural adjustments, perhaps a mindset that more resembles the culture in so-called high-reliability organizations (Weick and Sutcliffe 2007).

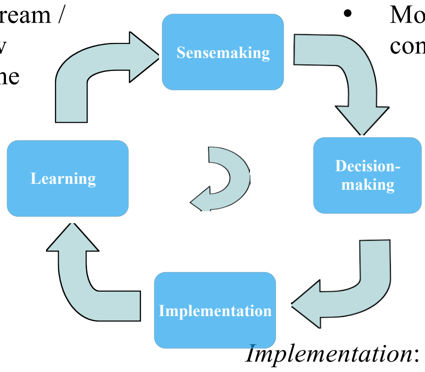
Implications for practice

Business tsunami are here to stay, so organisations had better learn how to live with them. What can companies do? A whole range of activities comes to mind, many of them again in analogy with what communities and countries do to mitigate the effects of tsunami. Broadly speaking, these can be classified in four categories, ranging from (1) the initial sensemaking of a tsunami event, to (2) the decision-making on how to deal with them, (3) the implementation of these decisions and (4) the learning from the tsunami after the fact. Together, these four categories form a management cycle, unfortunately often a sluggish cycle, and suitable policies will speed up this cycle. This cycle and sensible policies to speed it us are visualised in Table 4.

Table 4: Possible business tsunami mitigation policies

Sensemaking:
- Install advance warning systems ("condition-based maintenance")
- Look far & wide upstream / downsteam and below (avoid the Maginot line syndrome")
- Develop simulation models for scenario analysis

Decision-making:
- Develop end-to-end coordination processes (Sales & Operations Planning)
  - Move culture from "command and control" to "connect and collaborate"
    - Develop relevant theoretical frameworks on how to act ("Nothing more practical than a good theory")



Learning:
- Learn from near-miss incidents
- Foster a high-reliability culture mindset (c.f. Japanese tsunami mindset)
- Keep an open mind ("the mind of a ten-year old" like Tilly Smith)

Implementation:
- Prevent pressures from building up by timely response to them
- Increase the resilience of the supply network (increase its "Manning Number")
- Increase the agility to recover from major incidents ("Triple-A Supply chain")_

In *sensemaking*, we can learn from the variety of tsunami early warning systems in ecology (e.g., tsunami-alarm-system.com 2013). Another analogy is with the field of maintenance and asset management, where the use of sensors to monitor continuously the current condition of an asset is transforming this field. In general, the trick is to look far and wide. At KPN, there was just no monitoring of rework at managerial levels. At Airbus, there was a recurrent practice of disguising and not communicating delays and quality issues at every managerial layer. A key risk for managers is that they may be focusing on preventing the last "big thing", while the next one is inherently different, a practice we have labeled the "Maginot line syndrome".

In *decision-making*, it is key to have end-to-end coordination structures. In most cases, this will involve interorganizational decision-making, which often is very difficult to implement (c.f. Akkermans et al. 2004), but even effective intra-organisational coordination structures such as Sales & Operations Planning are often difficult to implement. A key role for OM researchers lies in developing good theories that companies can use to guide their actions. After all, there is nothing as practical as a good theory. This is where the current paper aspires to make a modest first start.

In *implementation*, it may be possible with business tsunami (not with ecological tsunami, unfortunately), to prevent pressures from building up in the first place. If KPN had paid timely attention to its rework backlog or if it had not ramped up so aggressively its new service in the first place, there would not have been a national outrage. If Airbus had not set such overly aggressive delivery schedules in an effort to outmaneuver Boeing, the A380 might not have been so very much delayed, since often one "needs to go slow to go fast" in new product ramp-ups (c.f. Mass and Berkson 1995, van Oorschot et al. 2010). If CISCO had dared to challenge some of the inflated orders from its demanding customers…. What is certainly possible is to make the network more resilient for when the tsunami wave arrives. In geography, this means increasing the Manning number, in OM we should develop something similar. Notions of supply network resilience (e.g. Christopher and Peck 2004, Sheffi 2005) and Triple-A supply chains (Lee 2003) certainly provide practical starting points here.

In *learning*, one is reminded of how the Japanese people reacted to the 2011 tsunami. Japan really has developed a tsunami mindset, which is not surpring after a history of over 190 recorded tsunami. One is equally reminded of the work by Weick and Sutcliffe on high-reliability organisations, that have learned to react effectively to situations of inherent unpredictability and high danger (Weick and Sutcliffe 2007). Also, one can look at the safety and reliability issue and start for instance with a systematic analysis of near-miss incidents (e.g. Dekker 2006, Reason 2008). A general piece of advice seems to be that acting timely is a matter of keeping an open mind, the example of ten-year old school girl Tilly Smith who saved her family's life by her timely response in the 2004 Asian tsunami can serve as a useful reminder here (Owen 2005).

Implications for research

In a narrow sense, the research implications from here onward appear straightforward. It seems obvious that we need to conduct:

- Research to identify tsunami and to make a taxonomy (e.g. using historical data, big data analysis);
- Research to study every type in the taxonomy (e.g. using system dynamics or even simple analytical models if possible).
- Research on tracking signals that would be good for early warning;
- Research on how to speed up the make sense and decide steps;
- Research on learning from the past (link with organizational learning systems).

In a broader sense, the research implications are much less straightforward, since they may require OM research to deviate from paths followed in recent years.

- We need to link OM research back to management: business tsunami are not "just" a supply chain thing, although they clearly have their roots and impact in operations, in the supply network.
- We need to link OM research back to managerial decision-making and to strategic management. The issues covered here range from marketing and financials back to public relations, from safety & reliability to interorganizational collaboration.
- We need to broaden our research methodologies, as clearly progress will depend on solid case-based research first, on simulation modelling to understanding these rare events and then on triangulation of different results form different research methodologies.

In a sense, these are not completely new thoughts for OM research. On the contrary, this would imply in some sense going back to our roots. Skinner (1969) observed back in the nineteen sixties already that operations was missing in the corporate strategy debate, and his own research brought OM straight back into the boardroom. Hayes and Wheelwright based their ground-braking research in the seventies and eighties on a series of carefully designed case studies of what various companies actually did (Hayes and Wheelwright 1984). In our present day, where Big Data offer opportunities in revealing tsunami and early warning signals in ways that were never possible before, this may be a very promising revitalised research strategy indeed.

9. Conclusions

Repeatedly, but infrequently, companies in high-clockspeed supply networks find themselves completely swamped by business tsunami: a flood of operations problems, which seem to be coming out of nowhere. Business tsunami occur rarely but most managers will be struck by them several times during their career, and they may shape their careers and the fate of the companies they work in. So, business tsunami are important and they need to be understood better. Business tsunami have some superficial similarities with the well-known bullwhip effect, but are just as different from them as on sea a tsunami wave is different from a normal wind-wave.

This paper has presented four different types of business tsunami but there probably are more, if not today then our present-day network economy may spawn them in the coming years. At any rate, the challenge for researchers and practitioners remains the same. We need to regain the strategic dimension of operations management and find the right indicators to follow to see tensions building up, we need to find out when and how to react to such tension buildup, we need to build in resilience in our networks and we need to learn better from our experiences with earlier business tsunami, greater and smaller. If we don't, there will continue to be suffering that could have been prevented.

References

Abdel-Hamid, Tarek K. and Madnick, Stuart E. (1991). *Software Project Dynamics – an integrated approach.* Prentice Hall, Englewood Cliffs, New Jersey.

Akkermans, H.A. and Vos, B. (2003). Amplification in service supply chains: An exploratory case study from the telecom industry. *Production and Operations Management* 12(2), pp. 204-223.§12

Akkermans, H., Bogerd, P. and van Doremalen, J. (2004). Travail, transparency and trust: A case study of computer-supported collaborative supply chain planning in high-tech electronics, *European Journal of Operations Research,* 153 (2), 445-456.

Akkermans, H.A., and van Oppen, W. (2006). Offensive KPIs: Improving buyer-supplier collaboration in interorganisational service supply networks. In: Conference Proceedings of the 24th International Conference of the System Dynamics Society. July 23-27, 2006 Nijmegen, The Netherlands. Accessed at www.systemdynamics.org on August 28. 2013.

Akkermans, H.A., & Voss, C. (2013). The service bullwhip effect. *International Journal of Operations and Production Management*, *33*(6), 765-788.

Autry, C.W., Golicic, S.L. (2010). Evaluating buyer–supplier relationship–performance spirals: A longitudinal study. *Journal of Operations Management* 28, pp. 87-100.

Business Week (2010). Intel's Forecast Shows Rebound in Technology Spending. *Business Week*, April 14, 2010.

Christopher, M. and Peck, H., 2004. Building the Resilient Supply Chain *International Journal of Logistics Management*, 15(2).

Computable (2005) : KPN start met VoIP voor consumenten, in Dutch ("KPN Starts with VoIP for consumers"), Accessed at www.computable.nl on August 25, 2013.

Computable (2007a). "Winstdaling KPN door Internetplusbellen", in Dutch ("Lower profits for KPN because of VoIP") Accessed at www.computable.nl on August 25, 2013.

Computable (2007b). KPN haalt deel ICT weer in huis, in Dutch ("KPN insources part of its ICT). August 3, 2007.Accessed at www.computable.nl on August 25, 2013.

Dawson, A.G. (1994). Geomorphological effects of tsunami run-up and backwash. *Geomorphology* 110, pp. 83-94.

Dekker, S. (2006). The field guide to understanding human error. Ashgate publishing, Farnham.

Flightglobal.com (2010) A350 schedule slips but Airbus still aiming for 2013 entry. Flightglobal.com November 12 2010, Accessed at www.flightglobal.com on August 28, 2013.
Gladwell, M. (2000). *The tipping point. How little things can make a big difference*. London, Abacus.
Hayes, R.H., and Wheelwright, S.C. (1984). *Restoring Our Competitive Edge: Competing Through Manufacturing*. New York: John Wiley.
Hopp, W. Spearman, M. (1996). *Factory Physics: Foundations of Manufacturing Management*, McGraw-Hill.
Kern, Th., L.P. Willcocks, E. van Heck, (2002). The Winner's Curse in IT Outsourcing. Strategies for avoiding relational trauma. *California Management Review* 44(2), 47-69.
Lee, H. L., V., Padmanabhan, V., and Whang, S. (1997). "The bullwhip effect in supply chains*", Sloan Management Review,* 38(3), pp. 93–102.
Lee, H. (2003) The triple-A suppy chain. *Harvard Business Review*, October 2004.
Little, J. D. C. (1961). A Proof for the Queuing Formula: L = λW. *Operations Research* **9** (3): 383–320.
Manning, R. (1891) : On the flow of water in open channels and pipes. *Transaction of the Institution of Civil Engineers* (Ireland).
Mass, Nathaniel J., and Berkson, Brad. (1995). Going Slow to Go Fast. *The McKinsey Quarterly* 4, 19-29.
Mastronuzzi, G., Brückner, H., De Martine, P.M., Regnauld, H. (2013): Tsunami from the open sea in the coastal zone and beyond. In: Mambretti S. (ed) *Tsanami. From Fundamentals to Damage Mitigation*. WIT Press, Southampton.
Nooteboom, B. (1996). Trust, Opportunism and Governance: A Process and a Control Model. *Organization Studies* 17(6), pp. 985-1010.
NYT (1999). Strong Growth Is Continued By Cisco Systems in Quarter. *New York Times* May 12, 1999. Accessed at www.nytimes.com on August 15, 2013.
NYT (2000). Cisco's $662 Million Profit Tops Forecasts. *New York Times* May 10, 2000. Accessed at www. nytimes.com on August 15, 2013.
NYT (2001a). Cisco Plans Steep Job Cuts And a Charge. *New York Times* March 10, 2001. Accessed at www.nyt.com on August 15, 2013.
NYT (2001b). Cisco to Offer 6-Month Severance. *New York Times* April 10, 2001. Accessed at www.nyt.com on August 15, 2013.
NYT (2001c) Warning by CISCO, an Internet titan. *New York Times* April 17, 2001. Accessed at www.nyt.com on August 15, 2013.
NYT (2001d) Did You Hear the One About the Superjumbo That Ate the Airport? *New York Times* Jan 28, 2001. Accessed at www.nyt.com on August 15, 2013.
NYT (2006a) The Airbus saga: Crossed wires and a multibillion-euro delay. *New York Times,* December 11, 2006. Accessed at www.nytimes.com on August 15, 2013.
NYT (2006b): Airbus Delay On Giant Jet Sends Shares Plummeting. *New York Times,* June 15, 2006. Accessed at www.nytimes.com on August 15, 2013.
NYT (2006c): Top Officials of Airbus and EADS Step Down. *New York Times,* July 3, 2006. Accessed at www.nytimes.com on August 15, 2013.
NYT (2006d): Airbus Faces More Delays For A380 Jet. *New York Times,* October 4, 2006. Accessed at www.nytimes.com on August 15, 2013.
NYT (2006e): FedEx Rescinds Order for Airbus A380s. *New York Times,* November 8, 2006. Accessed at www.nytimes.com on August 15, 2013.
NYT (2007a) Plans by Airbus to Eliminate Jobs and Shed Plants Set Off Labor Protests. *New York Times,* March 1, 2007. Accessed at www.nytimes.com on August 15, 2013.
NYT (2007b): First Loss Ever at Airbus, and Profit Drops at EADS. *New York Times,* March 10, 2007. Accessed at www.nytimes.com on August 15, 2013.
Oliva, R. and Sterman, J.D. (2001). "Cutting corners and working overtime: Quality erosion in the service industry", *Management Science*, 47(7), pp. 894–914.

Oorschot, K.E. van, Akkermans, H.A., Sengupta, K., & Wassenhove, L.N. van (2013). Anatomy of a decision trap in complex new product development projects. *Academy of Management Journal*, *56*(1), 285-307.
Owen, J. (2005). Tsunami Family Saved by Schoolgirl's Geography Lesson. *National Geographic News*, Jan 18, 2005
Reason, J. (2008). *The human contribution: unsafe acts, accidents and heroic recoveries*. Ashgate Publishing, Farnham England.
Reinhardt, C.M. Rogoff, K.S. (2011). *This Time Is Different: Eight Centuries of Financial Folly*. Princeton University Press, Princeton.
Sengupta, K., Abdel-Hamid, T.K., & Van Wassenhove, L.N. (2008). The experience trap. *Harvard Business Review*, 86(2).
Sheffi, Y. (2005). *The Resilient Enterprise. Overcoming Vulnerability for Competitive Advantage*. MIT Press, Cambridge MA.
Skinner, W. (1969). Manufacturing—Missing Link in Corporate Strategy, *Harvard Business Review*, May-June, pp. 29-37.
Sterman, J.S. (2000), *Business dynamics. Systems Thinking and Modeling for a Complex World*, McGraw-Hill, Boston.
Taleb, N.N. (2007) *The Black Swan. The Impact of the Highly Improbable.* Random House, New York. Weick, K.E. (1995) *Sensemaking in Organizations*. Sage Publications, Thousand Oaks CA.
TROS RADAR (2006a): KPN Internetplusbellen[11-09-2006], in Dutch ("KPN VoIP"). Accessed at www.tros.nl on August 8, 2008.
TROS RADAR (2006b): Opnieuw Internetplus bellen[04-12-2006], in Dutch ("Again, KPN VoIP"). Accessed at www.tros.nl on August 8, 2008.
Tsunami-alarm-system.com (2013), Occurrence of Tsunamis in the Pacific Ocean. Accessed at http://www.tsunami-alarm-system.com/en/phenomenon-tsunami/occurrences-pacific-ocean.html on Aug 23, 2013.
Tweakers.net (2007): KPN stopt reclame voor InternetPlusBellen (in Dutch: "KPN stops advertising for VoIP service") Accessed at http://tweakers.net on August 25, 2013.
Van Oorschot, K.E., Sengupta, K., Akkermans, H.A., & Wassenhove, L.N. van (2010). Get fat fast - Surviving stage-gate in NPD. *Journal of Production Innovation Management*, 27, 828-839.
Weick, K.E. and Sutcliffe, K.M. (2007): *Managing the unexpected. Resilient Performance in an Age of Uncertainty.* 2nd Edition, Wiley, London.
Wikipedia (2013a). *Tsunami*. Accessed at http://en.wikipedia.org/wiki/Tsunami on August 23, 2013.
Wikipedia (2013c): Minoan eruption. Accessed at http://en.wikipedia.org/wiki/Minoan_eruption on August 23, 2013.
Wikipedia(2013b) Chicxulub impactor. Accessed at http://en.wikipedia.org/wiki/Chicxulub_impactor on August 23, 2013.

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Supply Chain Knowledge Networking

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Abstract:
The astronomical growth and evolution of platforms such as Linked In, Facebook and Twitter reflect the success of Web 2.0 technologies; more importantly it illustrates how businesses and consumers will expect to interact with and use digital media in the future, for all sorts of reasons, including driving innovation. The KNOWNET project (An FP7 Marie Curie funded project) examines the potential of current social networking technology via an immersive 3D medium, to support sustained knowledge sharing and generation across a multi-level supply chain in the insurance market.

The aims and objectives of KNOWNET are to develop, build and test an interactive Supplier social network (SSN) framework, designed to support innovation and leaning where both explicit and tacit knowledge and experience of suppliers and their employees can be shared. The SSN will consist of a set of web based tools, applications and exercises supporting the formation of communities of inquiry and promoting learning through social interaction. Given that the idea of web based interactive SSN's is relatively novel, and a comparatively unexplored area in the field of SCM, the project seeks to measure participants attitudes and behaviours surrounding the concept of virtual supplier communities. It will explore the creation and sustainability of personal relationships, commitment and trust between parties, for the exchange of knowledge. Additionally, we seek to assess the value of social media tools to enhance supply chain knowledge collaborations and learning, and the use of SNA techniques to map and measure the relationships and flows of information/knowledge between individuals and groups within the various supply chains, and gain insight into the roles they play within the network.

The concept of collaborative networking is particularly timely in the insurance industry as it looks to strengthen the inter-organizational ties between its suppliers and external agencies, for improving processes, accelerating innovation, fostering creativity, and sharing experiences and local knowledge amongst its supplier networks. The research outputs will enable the industrial participants to assess the inherent value and efficacy of social networking as a knowledge sharing tool which can impact on a range of KPI's within a large supplier base, as well as provide opportunities for rethinking core processes across a breadth of insurance categories.
The KNOWNET academic industry collaboration will provide the type of expertise in learning via 'social networks currently not available within the European Insurance sector. The author believes KNOWNET's basic idea can be applied across a range of financial and manufacturing sectors.

Keywords: Supply chains, Knowledge networking, Insurance

Introduction

Knowledge is the foundation of a firm's competitive advantage and ultimately the driver of a firm's value (Bollinger & Smith 2001). Organizations therefore need to recognise it as being a valuable asset and develop a mechanism for tapping into the collective intelligence and skills of employees and supplier partners in order to create a greater organizational knowledge base (Bollinger and Smith 2001).

Despite this, most companies' today, regardless of location, size or industry sector are struggling with interconnecting knowledge, talent, ideas and relationships in their organisational environment and across their supply chains. Vital corporate knowledge is being trapped in information silos like email inboxes, functional silos, structured information systems like ERP, CRM and SRM, and more importantly within the minds of employees who create, recognize, archive, access and apply knowledge in carrying out their daily tasks (Nonaka and Konno 1998). Recent evidence shows companies' are beginning to consider web based 'social networking' as a community-building platform to sharing knowledge, (Bredl et al 2012; Annabi et al 2012; Álvarez et al, 2009) and reap the benefits knowledge networking can yield. Several past studies have emphasised the significance of wider supply chain networking for knowledge transfer- such as networking through supplier associations (Stuart et al 1998) and open innovation networks (Chesborough 2003), and more recently, online communities of practice Ardivilli et al 2005, Ardivilli 2008.

Supply chain management research increasingly is expected to make a significant contribution to the knowledge transfer and productivity debate, and indeed there is increasingly recognition that supply chains are beginning to prioritise knowledge creation and exchange (Wu 2008). Current literature suggests that the adaptation and implementation of successful ideas and practices can enable the development of innovative mechanisms, which in turn may result in productivity improvements (Edwards et al 2004). Successful management of a supplier network in particular can potentially enhance the productivity of the supply chain through diffusion of knowledge. Despite this, however, there remains a generally adopted view that the potential of SCM synergies for the creation and transfer of useful knowledge has not yet been materialised (Giannakis 2008). Extensive knowledge sharing still appears to be the exception rather than the rule (Lin 2005). Indeed, the findings of a recent study for the creation of value in organizations for example suggest that although firms in the UK for example, assign great importance to their suppliers as sources of new knowledge creation, their involvement in the generation of knowledge is low (Edwards et al 2004). There are a number of reasons and challenges associated with this. A key challenge concerns motivating supply chain members to engage in knowledge sharing and generating activities in the first place (Grant 2012, Ardichvili et al 2003), and a second challenge is the great difficulty in generating and transforming knowledge into organizational action, and subsequently it is even more difficult to transfer good ideas, insights and knowledge to supply chain partners (Capo Vicedo et al 2011).

Rationale for study

The KNOWNET project seeks to build on these challenges by specifically, developing, building and trialling a bottom up, user designed web based interactive environment - a Supplier Social Network (SSN), to support and facilitate exchange of good ideas, insights, tacit and explicit knowledge, innovations etc across a diverse group of suppliers within a multi level supply chain within the Insurance sector across two European countries.

To achieve these objectives, the collective expertise across interdisciplinary fields (SCM; KM, software engineering, SNA, e-learning and 3D web design) and the successful knowledge exchange between **Brunel University(BU)** and **Universitat Politecnica De Valencia (UPV),** and one private sector partner-**Royal & Sun Alliance Insurance PLC UK, (RSA),** was required. Collaborative inter-sectoral research was a critical success factor of the project as the conceptual models derived via the literature and pilot study, will be tested and modified with the close collaboration of the participant practitioners in the UK and Spain. As the framework will be developed via the close collaboration between industrial and academic partners, it will need to address the needs from both sectors, and provide ongoing opportunity where both the sectors organizations can collaborate for the update of the model in the future. Furthermore, the finalised framework needs to be verified in different countries and organizations, which have different cultures. As a result the consortium consists of partners from different EU countries and differing organizational cultures to execute the field trials in the UK and Spain. The research provides an opportunity to develop a long term strategic partnership between industry and academia across the EU in this field, with an emphasis on stimulating inter-sectoral mobility and increasing knowledge sharing through joint research industrial-academic partnerships in long term co-operative programmes.

General literature

The development and evolution of social networking sites such as Facebook, Linked In, Twitter etc, where people connect and collaborate, share personal experiences, and subjective insights, is fuelling the appeal of social networking for companies, where achieving close communities with employees, customers, and suppliers is difficult to accomplish (Khan & Khan 2012; Mangold & Faulds, 2009; Mayer, 2009; Yang & Chen, 2008). Such virtual communities can provide similar benefits to traditional social networking methods that enhance innovation and collaborative activity, but with the added advantage of speed, and free from boundaries of time or space (Ganley &Lampe 2009). Indeed, recent evidence shows companies' are beginning to consider web based 'social networking' as a community-building platform to sharing knowledge, (Bredl et al 2012; Annabi et al 2012; Álvarez et al, 2009; Tsai, 2009. A recent special report in the *Economist* stated that social-networking technologies are creating considerable benefits for the businesses that embrace them. The openness and richness of social networks can foster a fertile environment for the creation of entirely new knowledge, while also accelerating the innovation rate **(Majewski e**t al 2012) Seufert et al (1999).

Evidence shows that companies are seeking competitive advantages by using customised social networks as a community-building platform to share knowledge at speed and free from boundaries of time or space. Asda's recent launch of 'Sustain and Save Exchange' and Caterpillar Inc's 'Knowledge Network' are two examples of systems where opportunities for information, knowledge and learning's can be shared, questions raised, key documents posted, and focused activities attended, to spur new ideas and solve problems amongst members of a supply network.

Despite these developments and initiatives, factors leading to successful knowledge sharing especially online are not well understood (Chungsuk et al 2005 etc). Duan (2009) argues the theory of virtual internet communities for business generally is under developed, with a limited number of examples of social networking applications in the business context (Bulmer 2009) which continue to evolve as members and site owners experiment with them.

Whatever approach is adopted for sharing knowledge between individuals, whether face to face or online, the willingness of individuals to share knowledge is key. Knowledge sharing cannot be forced, but can be encouraged and facilitated (Gibbert and Krause 2002). Early studies have shown that employees often resist sharing their knowledge (Ciborra and Patriota,1998), variously defined as 'information hording' or as 'knowledge as a private individual's asset and competitive advantage' mentality (Mc Lure and Faraj2000). More recently, Archdivilli et al (2003) found the most important barriers to sharing amongst employees was a 'fear of losing face', misleading colleagues due to inaccuracies in the information, or irrelevancies in the information, not feeling like they have earn't the right to post on a company -wide system, a fear of criticism or ridicule of their postings'.

Additionally, studies found that knowledge does not flow easily when an organization makes a concerted effort to facilitate knowledge exchange (Szulanski 1996) and that knowledge exchange depends on an organization's culture and climate (DeLong and Fahey 2000). In addition assumptions about individuals' openness to virtual knowledge networks will vary from country to country

When designing knowledge transfer systems it appears then, important to consider the impact of the internal and external supply chain environment on motivation to knowledge sharing. Given the motivation to engage in sharing knowledge, insights into the views of multiple stakeholders are seen as crucial. There is a focus to this project which considers human networking processes and how they can encourage sharing and use of appropriate and relevant knowledge. Initiatives driven by IT alone ignore these factors (Ardichvili et al 2003;Scarbrough et al 1999).

Sharing community knowledge in the Insurance industry.

Conducting business in the financial services sector, requires collaboration across multiple parties within a supply chain. Indeed, for sectors such as insurance and banking, which depend on complex processes of multiple individuals exchanging information, knowledge, ideas, and insights, interaction, via social networks for example, could potentially deliver a huge set of efficiencies and opportunities for rethinking core processes.

Business in the financial services industry traditionally requires the input, participation and decisions of many stakeholders. For example, risk managers, actuaries, IT and marking/distribution staff often collaborate in product development. Lloyds of London uses collaborative technologies to cut claims costs for all the claims in the entire London Insurance market (Kontzer 2002). In motor vehicle claims processing, repairers, assessors claims staff, policy holders and legal representatives need to provide inputs and make decisions at different stages of the claims process (Tsui and Lee). Despite this need, and some minor developments in collaborative knowledge sharing, up to now, firms in the financial services industry are not seen as conducive to fostering knowledge sharing and generating collaborations across their supply chains in a pro-active way (Dawson 2004).

As knowledge exchange moves away from a complete reliance on face to face meeting, traditional e-mail and the exchange of documents, financial services, including Insurers are looking to incorporate collaboration technologies into their operating models, to improve process efficiency and knowledge sharing (Josefowicz 2011, Kontzer 2002). However, the use of such approaches and technologies presents a new set of challenges to these organizations, who are not used to managing knowledge transfer in this way. Included in these challenges are monitoring appropriate content for sharing or archiving issues, measuring the benefits of these new tools, integrating these new tools into existing workflow, communication and archiving systems and understanding the motivations prompting people to share knowledge or participate in virtual communities, in an industry that have typically always used private communication channels.

Social interaction encourages the sharing of ideas, discoveries, successes and failures and provides general social support (Chiu 2006; Wellman et al 2001; Leug 2003). These elements are often missing from traditional information portals. Individuals who are removed from a social interactive experience frequently feel isolated, start to lose motivation, experience frustration or anger (Wheeler 2007), and a host of other unwelcome emotions, which may lead to dropping out of the knowledge sharing and learning process (Martz and Shepherd 2007). In contrast, a virtual 3D environment requires an 'avatar' (human or other 'shape'), which can travel inside the virtual space and communicate with others in real time. The web 3D virtual world business application allows an 'immersive' experience, determined by the degree to which the user's senses are engaged, and the desirability and meaningfulness of the activity in which the user is participating (Nevo, S**.,** Nevo D., Carmel, E**..** 2011). Within the environment participants can communicate with each other via public or private voice chat, local or group or private text chat, messaging, document and object sharing, screen sharing, etc. The applications and information the user needs to complete a task for example have a meeting, deliver a presentation or collaborate on a model are accessible from and can be displayed within the virtual environment.

The social interactive environment also considers the interpretational process *of knowledge* through 4 distinctive consecutive stages (Gilbert and Cordey-Hayes 1996) through which knowledge is transferred. Cognitive IT led approaches to knowledge transfer typically fail to take into account such factors that lead different groups to have divergent, possibly even irreconcilable, interpretations of knowledge. The community view (Swan et al 1999) recognises that knowledge has to be continuously negotiated through interactive social networking processes. The community model emphasises dialogue occurring through active and systematic networking (which might be IT enabled), rather than linear information flows.

Social Network Analysis

In addition to building a socially interactive SSN framework, the project also uses social network analysis (SNA) techniques as a modelling tool to better understand knowledge management in a multi-level SC. The SNA perspective views any system as a set of interrelated actors or nodes. Actors represent entities at various levels of collectivity, such as persons, companies, countries, and so on (Borgatti and Li, 2009). Several authors propose SNA techniques (Boschma and Ter Wal, 2007; Borgatti et al., 2009) as appropriate to model business networks. In fact, there have been many previous works from supply chain management using these techniques (Carter et al. 2007; Mueller et al., 2007; Ozkul and Barut, 2009; Borgatti and Li, 2009; Choi and Wu, 2009; Bernardes, 2010). The use of SNA techniques in this project is expected to provide useful insights into how RSA's SSN can reinforce their collaborative behaviours and activities to not only enhance their relationships, but to also achieve competitive advantages for the SSN as a whole. The main aim of this project is to analyse the knowledge transfer process. We would like to have a knowledge network model represented within SNA techniques which enables us to gain a better understanding of the knowledge creation and transfer process.

Another objective is that each company in the SSN not only focuses on its own processes, but also views the global process of the entire SSN working as a single body. They can compete against other SSN and satisfy clients' needs. This exchange allows for personal and physical communication among people in the various SSN companies, thus creating a social network.

This project also focuses on analysing how establishing these inter-organizational relationships into networks, leads to knowledge exchange among the companies under study, and to the creation of new specific knowledge by promoting confidence and motivation and by establishing alliances, team spirit and better coordination and communication among the enterprises involved. Research has shown that using social networks leads to a higher degree of innovation, fewer losses, improved efficiency in transactions, and to increased competitiveness (Capo Vicedo 2011), and these features will be examined among the companies in the SSN.

Methodology

The KNOWNET project will be implemented in 3 phases.

In phase one, the consortium partners will engage in exchanging knowledge to initially develop, build and test an interactive Supplier Social network, prior to conducting parallel trials in the UK and Spain to assess its knowledge transfer capability.

In Phase two, the consortium will identify 'optimal knowledge exchange and transfer tools, applications and exercises within the digital, web 2 and 3D virtual world environments, subsequent to evaluating user engagement and knowledge transfer capability of the provisional integrated system.
Phase three will measure knowledge adoption and transfer capability within the revised framework, prior to finalising the platform.

The figure below outlines the 3 phases of the programme

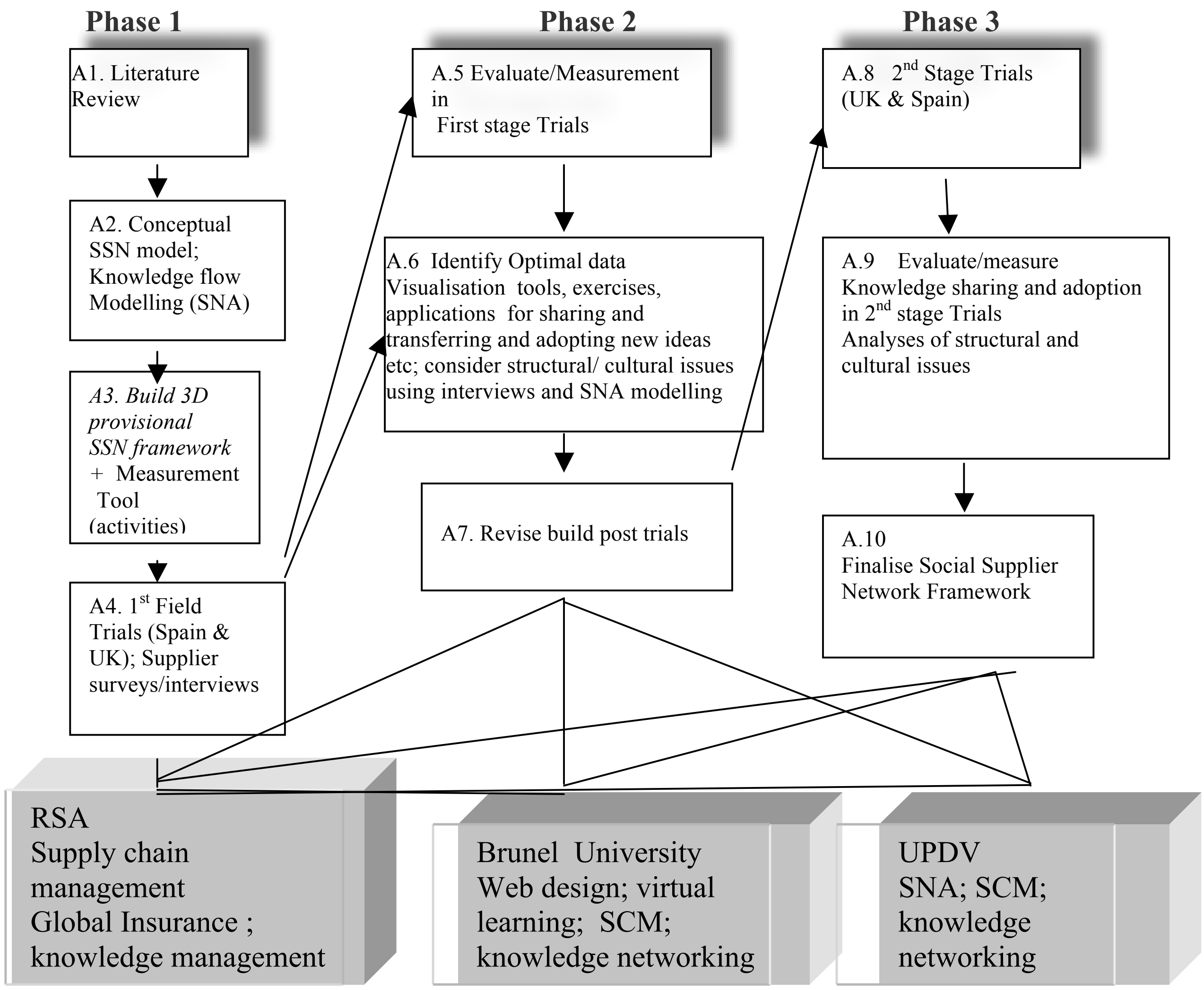

Figure 1 Methodology and Partnership

As shown in figure 1 the research programme will be implemented via 3 phases. Developing, building and testing an interactive Supplier Social network; identifying 'optimal knowledge exchange /transfer tools, applications and exercises incorporating data visualisation, and finally measuring user engagement and motivation to knowledge exchange/generation and value added using a web 3D immersive medium.

In phase 1, the key activities are to develop, build and test a provisional SSN platform. Development of a conceptual SSN model will be based on a literature review and results from a recent pilot on attitudes to SSN engagement across a motor insurance supply chain in the UK and social networking analysis theory. This will be conducted jointly by Brunel University and Universitat Politecnica De Valencia.

The major output of **phase 1** is to develop and build the provisional SSN framework (incorporating web based tools, etc) that enable diverse supply chain partners from distinct insurance supply chains in the UK and Spain, to interact for the purposes of knowledge transfer. Various facilities and tools will be constructed.

The virtual world environment will facilitate the activities and exercises that will be used to promote knowledge transfer. These include buildings, social areas, team-building tools and applications, and will involve design, construction, scripting, implementation and testing to facilitate the activities required. The first trial will log data on supplier engagement and usage, as well as survey supplier satisfaction and attitudes to interaction within the 'immersive' environment. The trial will run over a period of three months. The project will also carry out social networks analysis (SNA) techniques to model knowledge flows across the multi levels of the Supply chain. The SNA modelling should reveal the structural properties of the network and the implications of these structural properties for the design of social network based systems. Engagement with the platform over the trials will provide an opportunity to study the characteristics of online social networking and an understanding on how to improve/modify a later version of the SSN. The major tasks will be to classify lessons from the initial field trials and literature for the enhancement of a later trial and other domains.

In Phase Two, the major task of this phase will be to identify the best '3D interactive tools, develop a range of team building activities, and exercises' capable of promoting the sharing of good ideas, and knowledge transfer through social interaction. A variety of different tools, processes and activities will be designed, developed and tested (iteratively) to identify the optimum range of the knowledge transfer tools. This will follow from the initial field trial and evaluation of the trial results. The provisional SSN will be revised in the light of the findings from the initial trial.

The key activities in **Phase 3** will be to measure knowledge transfer and knowledge adoption within the revised SSN framework. A key activity in this phase is to run a range of virtual 'simulations', and exercises using data visualisation, as a tool for measuring knowledge transfer across participants. Participants will then be surveyed/interviewed to ascertain ease of use and satisfaction with the tools, the acquisition of new content (via leaning by doing), the acquisition of new insights (via learning from others, discussion), and follow-on exercises later in the trial to measure ability of participants to implement the new content gained from the interaction with other participants and tools/exercises.

Another activity will involve identifying structural/cultural inhibitors and enablers' to engagement and interaction using interviews, surveys and continued SNA modelling during the field trials in both phases. The findings from the second trials in phase 3 will define the generic constructs of the 'knowledge sharing SSN' determine its' usefulness across other domestic domains, and refine the evaluation tool. This tool will continue to monitor and measure engagement and usage, supplier feedback and the impact of the different learning processes and tools on the depth and breadth of knowledge transfer, motivation to share ideas, etc.

The SSN framework will be applied to a number of participants (primarily SME's) within a multi-level supply Insurance chain in Spain and the UK. Phase 3 aims to refine and validate the framework developed in phase 1 and evaluate this interactive medium for transferring ideas, insights, experiences and learning from others. The trial also allows researchers to explore structural (using SNA analysis) and cultural differences across the 2 groups. The SSN needs to be verified in different countries having different cultures. As a result the consortium consists of partners from different cultures to execute the field trials in the UK and Spain. If the SSN is shown to promote knowledge networking (knowledge exchange and generation and learning) across the partners cultures, then it is felt that a similar framework using web based tools and applications, would be accepted by a number of other countries with similar cultures, within the EU.

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Bibliography

Alvarez, I., Marin, R.,& Fonfría, A (2009) The role of networking in the competitiveness of firms. Technological Forecasting & Social Change. Vol.76

Annabi, H.; McGann, S.T.; Pels, S.; Arnold, P.; Rivinus, C. (2012),Guidelines to Align Communities Practice with Business Objectives: An Application of Social Media (HICSS), 2012 45th Hawaii International Conference on System Science

Ardichvili A, Page V and T Wentling (2003) Motivation and barriers to participation in virtual knowledge sharing communities of practice' Journal of Knowledge management Vol 7 iss1 pp64-77

Borgatti SP, Mehra A, Brass D, Labianca G. Network Analysis in the Social Sciences. Science 2009; 323(5916): 892-895.

Boschma RA, Ter Wal ALJ. Knowledge Networks and Innovative Performance in an Industrial District: The Case of a Footwear District in the South of Italy. Industry & Innovation 2007; 14(2): 177-199.

Bernardes ES. The effect of Supply Management on aspects of Social Capital and the impact in performance: a Social Network Perspective. Journal of Supply Chain Management 2010; 46(1): 45-56.

Bulmer, D. (2009) Social Networks and B2P.

Bollinger A S and R Smith (2001)'Managing organizational knowledge as a strategic asset' Journal of Knowledge Management Vol 5 Iss1 pp8-18.

Bredl K, Grob A, Hunniger J and Fleischer J(2012)'the Avartar as a Knowledge worker; How immersive 3D virtual environments may foster knowledge acquisition' Electronic Journal of Knowledge Management vol 10 issue 1 pp15-25

Capó-Vicedo J , J Mula, J Capó, (2011) "A social network-based organizational model for improving knowledge management in supply chains", Supply Chain Management: An International Journal, Vol. 16 Iss: 4, pp.284 - 293

Carter CR, Ellram LM, Tate W. The use of social Network analysis in Logistics research. Journal of Business Logistics 2007; 28(1): 137-168

Chesborough H(2003)'Open Innovation: The new imperative for creating and profiting from technology, Harvard Business School Press Cambridge MA.

Choi TY, Wu Z. Triads in supply networks: Theorizing Buyer-supplier-supplier relationships. Journal of Supply Chain Management 2009; 45(1): 8-25

Chungsuk R, Kim Y, Abhijit C & Raghav R(2005)'knowledge acquisition via three learning process in enterprise information portals: Learning by Investment, learning by doing and learning from others' MIS Quarterly june 2005 vol 29 issue 2 pp245-278

Chiu C, Hsu M; Wang E (2006)' Understanding knowledge sharing in virtual communities: an integration of socisl capital and social cognitive theories' Decision support systems 42

Ciborra C and G Patriota(1998) 'Groupware and teamwork in R&D' R&D management 28 (1) pp1-10

Dawson R(2004)Review of the collaborations in the Financial services conferences2004, 29th September 2004 URL=http://www.aht.com.au.

Dede C(2009)'Immersive Interfaces for Engagement and **Learning'** Science 2 January 2009: Vol. 323 no. 5910 pp. 66-69 DOI: 10.1126/science.1167311

DeLong D and Fahey L (2000)'Diagnosing cultural barriers to knowledge management, vol 14 no4.

Duan, W. (2009) Special issue on online communities and social networks: An editorial introduction. Decision Support Systems. Vol.47, 167-168.

Edwards T, Battisti G and Neely A (2004)'Value Creation and the UK Economy: A review of strategic Options' International Journal of Management Reviews Vol5/6 No3/4 pp191-213.

Edwards T, Battisti G and Neely A (2004)'Value Creation and the UK Economy: A review of strategic Options' International Journal of Management Reviews Vol5/6 No3/4 pp191-213.

Ganley, D., and Lampe, C. (2009) The ties that bind: Social network principles in-online communities. Decision Support Systems. Vol.47, 266-274.

Giannakis M(2008)'Facilitating learning and Knowledge Transfer through Supplier Development' Supply Chain Management: an International Journal Vol 13, issue 1 pp62-72.

Gilbert M and M Cordey-Hayes(1996) 'Understand the process of knowledge transfer to achieve successful technological innovation' Technovation Vol 16, no 6 pp301-12

Grant S B Exploring attitudes to knowledge networking in UK insurance supply chains(forthcoming) 2012

http://en.wikipedia.org/wiki/Virtual_world

JosefowiczM (2011) Sharing alike: Insurers need to figure out how to use new collaboration tools' INN SIGHT page 28 Vol 14 no.7

Khan A and , R Khan, (2012) "Embracing new media in Fiji: the way forward for social network marketing and communication strategies", Strategic Direction, Vol. 28 Iss: 4, pp.3 - 5

Kontzer T (2002)'Come together- companies are collaborating to save money, save time, and drive new business' Information Week October 7th 2002.

Kotabe M, Martin X, Domoto H(2003)'Gaining from vertical partnerships: knowledge transfer, relationship duration and supplier performance improvement in the US and Japanese automotive industries, Strategic Management Journal vol 24, no 4 pp293.

Leug C (2003) Knowledge sharing in online communities and its relevance to knowledge management in the e-business era' international journal of electronic business Vol1 no2 pp140

Lin and Wu (2005)managing knowledge contributed by ISO 9001:2000, International journal of quality and reliability management Vol 22 no.9

Majewski G , **Usoro** A and **I Khan** (2012) Knowledge sharing in immersive virtual communities practice Vol 41 issue 1 VINE

Mangold, W.G., and Faulds, D.J. (2009) Social media: The new hybrid element of the promotion mix. Business Horizons. Vol.52, 357-365.

Martz and Shepherd (2007)'Managing distance Education for Success' International journal of web-based learning and teaching technologies vol 2, issue pp50

Mayer, A. (2009) Online social networks in economics. Decision Support Systems.Vol.47, 169-184.

McLure Wasko m and S Faraj (2000) 'it is what one does..' Journal of strategic information systems 9 pg 155

Mueller RAE, Buergelt D, Seidel-Lass L. Supply Chains and Social Network Analysis. 1st International European Forum on Innovation and System Dynamics in Food Networks, 2007; 1-12.

(Nonaka I and Konno N (1998). The concept of 'Ba': building a foundation for knowledge creation' California Management /review vol 40 no3. Pp40

Nevo, Saggi, Nevo Dorit, Carmel, Erra. Unlocking the Business Potential of Virtual Worlds. **MIT Sloan** Magazine: Spring 2011**. March 23, 2011**

Newell, S., and Swan, J. (2000) Trust and Inter-organizational Networking. Human Relations. Vol.53 No.10, 1287-1328.

Ozkul A, Barut M. Measuring supply chain relationships: a social network approach. International Journal of Integrated Supply Management 2009; 5(1): 38-61.

S Wheeler (2007)in Moore, M. G. (1972) Learner autonomy: the second dimension of independent learning. Convergence, 5 (2) 76-88

Scarbrough H, Swan J, Preston J(1999)'Knowledge Management and the learning organization' IPD London.

Seufert A, G V Krogh and A Bach (1999).'Towards knowledge Networking' Journal of knowledge Management Vol 3, no 3 pp180-190

Stuart I, Deckert P; Mc cutcheon D and Kunst R (1998) 'Case study: a leveraged learning network' Sloan Management Review Vol 39, no 4 pp81-93

Swan J, Newell S, H Scarbrough and D Hislop(1999)'Knowledge Management and Innovation: networks and Networking' Journal of knowledge Management Vol 3 issue 4 pp262-275

Szulanski G(1996)' Exploring internal stickiness: impediments to the practice of best practice within the firm' Strategic management journal 17 27-44 special issue

Tsai, K (2009) Collaborative networks and product innovation performance: Toward a contingency perspective. Research Policy. Vol.38, pp765-778.

Walter, J., Lechner, C., & Kellermanns, F.W. (2007) Knowledge transfer between and within alliance partners: Private versus collective benefits of social capital. Journal of Business Research. Vol.60, 698-710.

Wu C (2008) Knowledge creation in a supply chain' Supply Chain management: An international Journal, Vol 13, no 3 pp241-250

Yang, S.J.H., and Chen, I.Y.L. (2008) A social network-based system for supporting interactive collaboration in knowledge sharing over peer-to-peer network. International Journal of Human-Computer Studies. Vol.66, 36-50.

Design Management in the Textile Industry - A Network Perspective

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Abstract

In this paper we explore textile design activities and textile design management from an industrial network perspective. The textile industry is probably one of the most globalized manufacturing industries in the world and thus one of the most dispersed industries on the globe.

Most studies on design management are framed inside the organisational context of the firm. In this study the role and practice of textile design is addressed in perspective of the global textile production network. The empirical data stems from six case studies exploring how different types of enterprises are organised in larger networks of suppliers, customers and other relations.

Comparing the organisational networks we discuss how design activities unfold under different organisational settings. We also demonstrate that it is crucial for the companies who rely on external production facilities to have a strong design management in order to maintain the relationships in their network of customers and suppliers.

Keywords: Design management, textile industry, design activities, organisational networks

1. Introduction

Designing a product, a service or combinations hereof also means designing those activities required to produce the artefact. Therefore, the role of design has to be analysed in close conjunction with the production activities performed. The way they are organized, staffed and equipped is influenced by and influences the design process. This is clearly the case in the organisations under scrutiny in this study.

In a seminal study Rachel Studd (2002) has analysed similarities and differences in the organisational setting and managerial practices exercised in a number of UK textile enterprises. A major conclusion from the study is:

"Design does not happen by accident but as a result of an understood and well-managed process by the designers along with effective communication between all relevant participants" (Studd, 2002: 47).

Studd is primarily concerned with the design processes taking place inside the organisational boundaries of the firm. She doesn't include the influence on the design process that comes from foreign affiliates as well as the outsourcing of manufacturing activities to an international network of suppliers. In this light we add the following question to the quote referred above: Who are the relevant participants and how are they managed? This is an important question in light of the sophisticated specialization in the textile industry and hence the way design processes are organized across the boundaries of the individual enterprises. On this basis we have formulated two key research questions: 'How do design activities unfold under different organisational settings?' and 'How does the role of design management change when design breaks through and crosses organisational boundaries?' A major concern is the role played by design in configuring the value-creating networks in the global textile industry. No simple answer can be expected, but the ambition is to pave a path to future studies providing a finer-grained image.

The global division of labour in the textile industry has been radically transformed during the past 25 years. Former strongholds of textile production have been abandoned leading to a global shift not only in the spatial patterns of textile production, but also radical shifts in the task partitioning of design and the role of design management. This transformation has impacted the way design activities are organized and the competencies needed to perform design processes. While the management of design is traditionally seen as a matter of directing and coordinating in-house activities and internal resources of the organisation, design management turns into a matter of coordinating activities and resources embedded with a network of actors constituting the value chain reaching from raw materials, across diverse stages of processing and refining to the final stage of producing and distributing the textile artefact. Designing thus takes place in an open and dynamic organisational framework in which the options for how to organize design and production are more open than previously. In this flexible network of actors design seems to assume a new role in configuring collaborative ventures in the textile industry.

The field of textile design and design research has produced a diverse amount of literature about the textile design process and the profession (among them Albers, 2000; Fiore & Kimle, 1997; Gale & Kaur, 2002; Studd, 2002; Wilson, 2001). The emerging Danish field of textile design research has also made a valuable contribution (Bang, 2010; Riisberg, 2006). However, in our view the current textile design literature tends to explore the design process and design activities in an internal organisational framework or from an individual analytical perspective. Since most textile companies configure their operations in a network of organisations, we see a need to cover the analytical gap with studies of the design activities and design management from a network perspective (Bang & Christensen, 2011; 2013). We find that further knowledge about the design activities and design management in a network perspective will contribute to more versatile studies that are concerned with the organisational and individual textile design process and activities.

In this contribution we have identified six Danish textile enterprises in order to provide an initial empirical insight into the role of design and design management seen from an industrial network perspective. The case studies are characterized by different ways of employing design and of organising production, sales and development work. Thus the role of design as a foundation for coordination, knowledge exchange and control, i.e. the role of design as a managerial tool in the business network, also varies considerably.

2. The Global Textile Production System

Before we present the case studies, an outline of the global textile production system is provided. Over the years Peter Dicken has examined the textile and clothing industries in a global perspective (see for example Dicken, 2003; 2011). We therefore find it appropriate to base an overview of the industrial context on his work. For this paper we have chosen to use the 2003 edition of his book since it addresses the textile (and the garment) industry (Dicken 2003). It should be noticed that since this edition another two editions have been published, but they have a more specific focus on the clothing industry.

According to Dicken the textile and clothing industries were "the first manufacturing industries to take on a global dimension" (2003: 317). The textile industry is probably one of the most globalized manufacturing industries in the world and thus one of the most dispersed industries on the globe. The textile production system is complex, based on a diversity of primary sources and directed to diverse ends. Each stage from primary sources to final ends has technological as well as organisational and geographical endeavours of their own. Changes have been and still are substantial. For example the 2011 edition of Dicken's book describes the 2005 termination of the Multi-Fibre Arrangement, which since the 1960s had regulated the trade in the textiles and clothing industries (Dicken 2011).

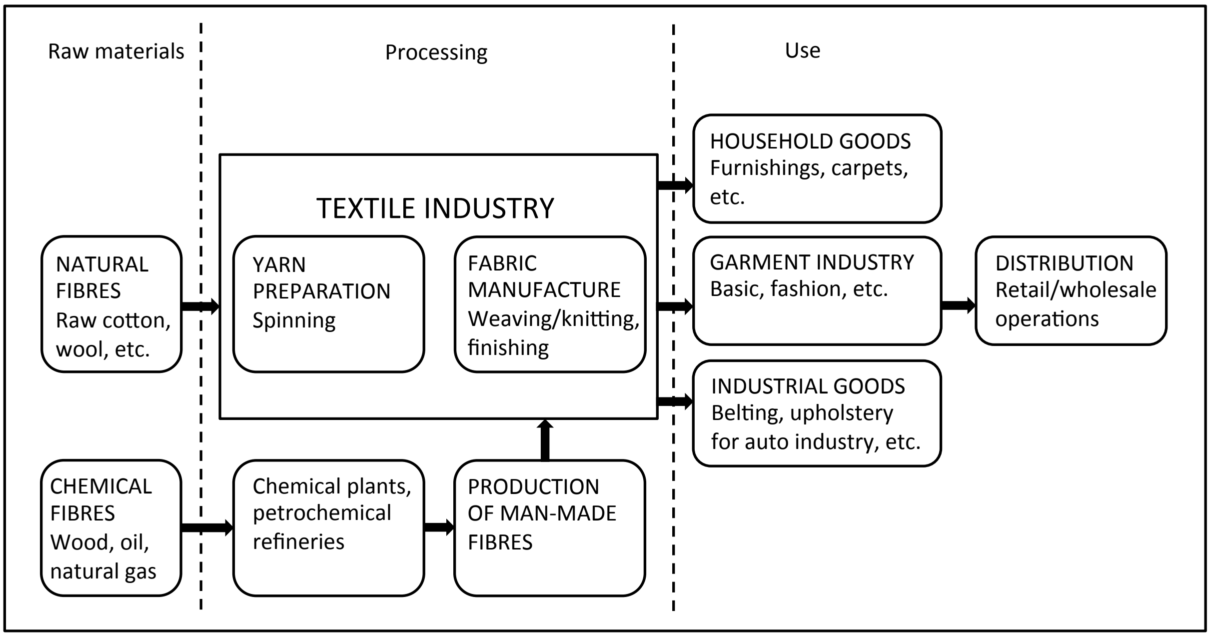

Figure 1: The textile production system (based on Dicken, 2003: 318).

Figure 1 represents Dicken's understanding of the textile industry and how it operates and serves within a larger value chain. Dicken suggests that the textile industry is limited to yarn preparation and fabric manufacturing and indicates how these processes feed into the production processes of end use in three segments; household goods, the clothing industry and industrial goods. Dicken further acknowledges that each stage presented in the figure has its own characteristics technologically, organisationally and geographically (Dicken 2003). As such the chart provides a useful overview of the diversity of the global network at stake.

What we will try to reveal in this paper is that underneath the aggregated surface of the global textile production system a highly detailed and diversified image is found. Specialization and division of labour in the international production and value-creating network is extremely fine grained. Huge differences are found between those segments of the industry serving the clothing industry and those serving industrial customers like for example the automobile industry on one side and the institutional markets like the market for interior textiles in offices, hotels and similar institutions on the other side. Even within the three mentioned segments huge differences can be found.

In this paper we attempt to give a glimpse of the complexity through the exploration of a selection of globally oriented enterprises within the Danish textile industry. Our main interest is to look into the role of design and its implication for organisational and managerial complexity since these activities seem to play an important role when the production facilities are located outside the company.

3. Network Theory

The theoretical framework for our study is the business network theory, and we take our starting point in the work of the so-called Uppsala model. The Uppsala model has contributed with a conceptual framework for the analyses of relationships and networks on the analytical level of organisational units (see Håkansson & Johanson, 1992; 1993; Håkansson and Snehota, 1995 and Håkansson et al., 2009). The conceptual model is often called the ARA model, denoting three layers of substance in relationships between organisations, namely Activities, Resources and Actors. In an actual industrial setting there is a strong interdependency between these three elements. Therefore it is relevant to discuss industrial networks as a type of governance mode taking place between the market and the hierarchy of the organisation. The model is reproduced in its basic form in figure 2 below.

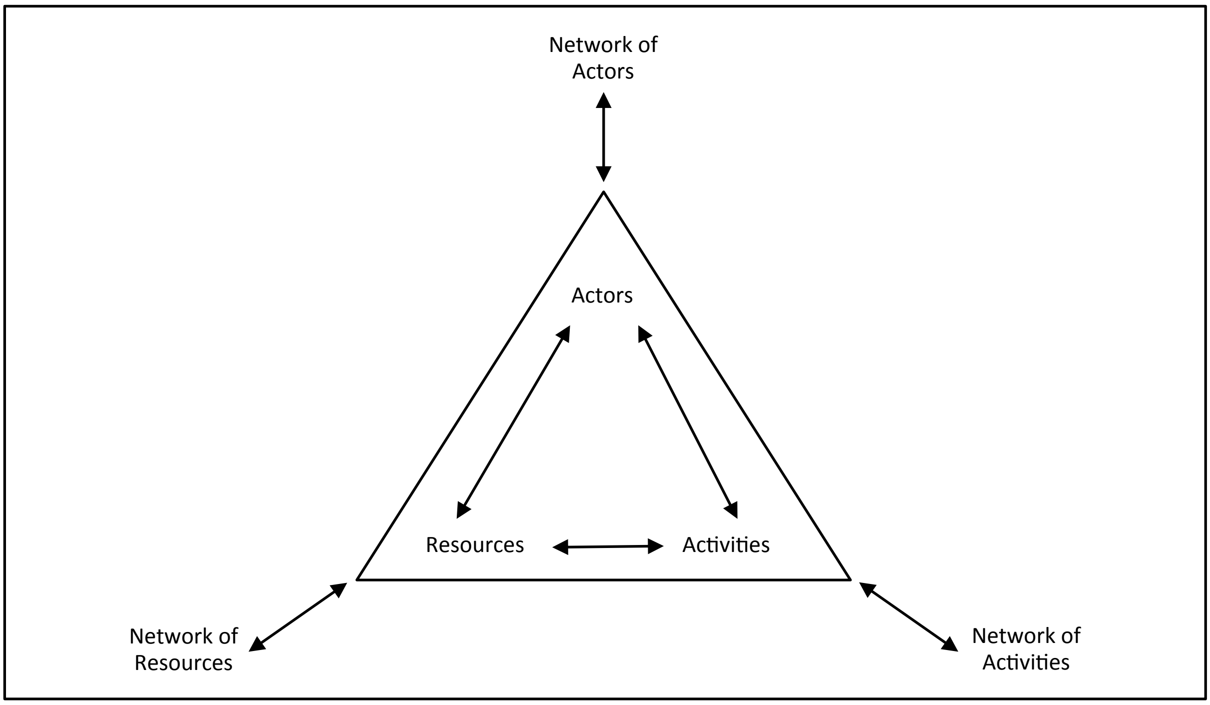

Figure 2: Interplay of the three layers of substance in relationships between organisations: activities, resources and actors (based on Håkansson & Johanson, 1992:154)

Actors control activities and resources. An actor can be an individual, a department in a company or a whole company depending on the analytical perspective taken. Actors combine various activities in order to create value. Combined activities lead to transformations, implying that actors' resources are combined and changed. Activities controlled by one actor depend on the activities of adjunct partners in order to extract value from the existing resources. Thus, value creation is founded in combinations of actors.

Actors also possess different resources (financial; knowledge; competencies etc.). In order to extract value from these resources they are combined with resources from partnering actors and stakeholders. Actors will often experience that resources of their own do not pose value except in combination with resources possessed by other partners. It is thus important for actors to gain access to external resources through the joint organisation of activities.

When actors carry on activities, they relate to other actors and develop bonds with them. Activities demand resources, internal as well as external to the actor. The access to resources limits the type and range of activities single actors can undertake. On one hand a bond between actors is seen as a prerequisite for the development of activity links and resource ties. On the other hand activity links form the development of bonds between actors and resource ties. Finally – in regard to resources – more or less lasting ties are developed supporting activity links and bonds among actors. Håkansson and Snehota view the interplay between actors' bonds, activity links and resource ties as the dynamic source for change and development in relationships. It is an on-going process of mutual exchange and adaptations among the stakeholders joining the network. The exchange and adaptations processes may for example include social, informational and economic exchange and adaptation processes.

A number of issues will frame the exchange and adaptation processes among actors. Situational factors and relationships to third parties related to the actors involved are some key issues, but institutional and cultural factors will also frame the interaction, as will, of course, outcomes of transactional episodes among the actors involved. Through transactional episodes, actors expand their experiential knowledge of each other, which will contribute to shaping the atmosphere in the relationship building, including mutual trust building. One of the critical issues framing industrial networks is the asymmetries existing among the actors involved. Different types of asymmetries are at stake.

Information asymmetries may influence the way actors bond, while asymmetries in for example legality may influence the allocation of activities among the actors and asymmetry concerning resources in control may influence actors' perspectives on viable opportunities and how to exploit them (Bjerregaard and Christensen, 2008).

4. Empirical Data and Research Methods

As already mentioned, the objective of this study is to generate knowledge about design activities and design management in the textile industry. The empirical data is based on a selection of six companies within the Danish textile industry. The inquiries focus on each organisation within a larger (international) network paying special attention to the role of design management in building interactive design processes among the enterprises in the network. The companies represent different ways of designing, manufacturing and distributing interior, household and furniture textiles.

The fieldwork was conducted as semi-structured interviews with design managers and designers at the respective companies' domiciles. Furthermore public material (digital and paper-based) has been included in the analyses. One case draws on an existing report and does not (yet) include field studies. Each interview lasted approximately one and a half hours and was audio-recorded. All interview agendas – though slightly different – included the following themes:

- Basic knowledge about the company concerning design strategy, production activities, suppliers and key customers

- The design process, including questions about design briefs, procedures, formalisation and stakeholders
- Design management, including questions about briefing, initiating, coordination, decision-making, finalisation and formalisation
- Cultural aspects, including questions about interaction between stakeholders, cultural differences, and management of a process, which are shared among several organisations and/or stakeholders

Due to space limitations in this paper we chose to provide shortened versions of the case studies. We also chose to anonymise the companies in order to enhance the focus on the organisational network rather than the single company. We are especially concerned with design activities and ways in which design contributes to collaboration within the network of organisations. Another main interest is how the location of the production facilities and thus the interaction between sites of production and design influenced the design processes. The core of our analyses focuses on the changes in designing and design management taking place when production and development activities are distributed among actors in international value creation chains.

Each case starts with a brief background description of the company. Subsequently we explore task partition among actors in the design process and how task partitioning influences the way design is governed. This is followed by a description of the design activities. Finally we investigate the management of the task partitioning as seen from the perspective of the organisation in focus. Each case description concludes with a diagram that roughly maps the company in a larger network of production, design, main customers and end-markets.

5. The Six Case Studies

5.1 Company 1

Company 1 (C1) started as a local Danish textile mill in 1851. Today C1 is a globally oriented enterprise that designs, develops and sells fabrics and textile solutions to the international furniture industry. Originally the company hosted production facilities in-house, among them weaving, dyeing and spinning. Since the late 1990s all production has been gradually outsourced to manufacturers in other European countries and the Far East. Today the core activities in the house of C1 are organised within several 'independent' business units, among them an in-house design department and key account management. The company only occasionally engages with external designers.

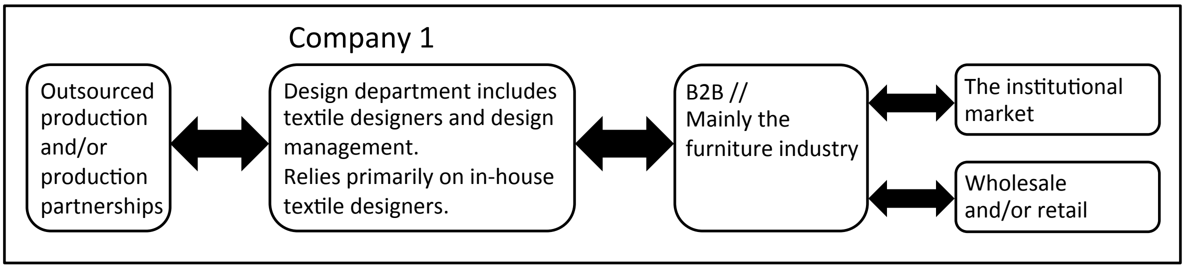

Figure 3: Company 1 primarily relies on in-house textile designers, its main customers are companies in the furniture industry.

In C1 designers and key account managers in particular are responsible for market surveillance and maintaining customer relations. Development of new products and services is initiated when a customer need is identified and the standard collection fails to fulfil the requirements. Often new products are developed in close collaboration with a specific customer.

Among the designer's main responsibilities are construction, aesthetics and colourways, and the designer also serves as a project manager during specific phases of the development process. In C1 the designer also contributes to maintaining contact to suppliers primarily tracking the development of new materials and techniques. During the development process the designer is also involved in aesthetic and functional approval of samples, fabrics etc. in collaboration with selected external supply units. The designer in C1 often has close collaboration with the staff in the customer's design and development department. Finally the designer works closely with other in-house business units in addition to the key account management, e.g. the quality, sales, logistics, and marketing departments.

C1 uses design management to create strong, long-lasting relationships with a number of their key suppliers. The tight collaborative bonds help to gain access to material knowledge formerly placed in-house, technical resources, and insights into aesthetic trends placed outside the ownership of C1. On the other hand C1 gains early insights into new trends and innovation challenges in the market for furniture fabric by help of their close partnering with large international key customers. However, a major shift has taken place in available management incentives, since activities to be co-ordinated and managed are now placed outside ownership control.

5.2 Company 2

Company 2 (C2) was established in 1870 and is still owned and managed by the founding family (5th generation). It is mainly oriented towards the European market. Originally the company was established as a traditional textile manufacturer. Today all production has been outsourced in production-partnerships and the core business of the company is design, development and marketing of textile household products, e.g. tablecloths, bed linen etc. C2's key customers are linen rental enterprises serving large public and private institutions. The company aims to be the preferred supplier of linen to European leasing laundries. Thus design efforts have a strong focus on contributions to the functionality and rationality of the laundries' business while also providing aesthetic value to end-customers, which in this case are hotels, hospitals, restaurants etc. C2 consists of several departments among them a combined design and marketing department.

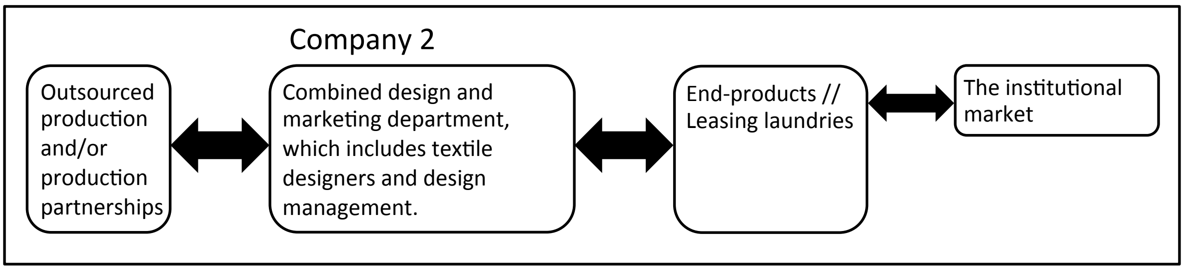

Figure 4: Company 2 relies on in-house textile designers; its main customers are leasing laundries.

In C2, design and marketing are the primary department responsible for market surveillance. The company is market-driven and much energy and time is spent on developing concepts that meet the demands of the leasing laundries. C2 is dependent on technological innovation in order to meet the functional standards of laundries. Even though C2 has a strict focus on these standards, the marketing strategy is to communicate the emotional benefits of the textiles to the end-customers.

The designer's key role is to create collections and pattern families that both imply a pleasant end-user experience and fulfil the laundries' and the end-customers' functional demands. Thus, among the designer's main responsibilities are the design of construction, aesthetics and colourways. Additionally the designer follows the technical/functional development of raw materials at the international production-partners very closely. There is also close collaboration with the in-house strategic product development, which is in another department. Likewise the designer has a close relationship with the leasing laundries as well as thorough knowledge about the end-customers. Thus, the designer is able to combine high functionality with aesthetics and thereby contribute to the marketing strategy of communicating the emotional benefits of C2's products.

C2 uses design management to gain a position as a preferred design partner for leasing laundries in Europe. This is done by means of a service-minded design of textiles optimising the service that laundries can provide for their customers. C2 itself is also a customer, since it constantly demands innovative textile solutions from its suppliers and production-partnerships. This in turn limits the number of international suppliers the company relies on. C2's in-depth knowledge of laundry service requirements helps to develop suppliers' material knowledge and technical resources. This in turn enables C2 to have a unique position to suppliers' resources.

5.3 Company 3

Company 3 (C3) is a globally oriented enterprise that manufactures carpets for institutional markets all over the world. This includes hotels, conference centres, airports, hospitals etc. C3 also sells to wholesale businesses on a limited scale. The collection includes wall-to-wall carpets, carpet tiles and rugs. Additionally C3 offers to design and produce customized carpets in collaboration with the customer. The company was established in 1938 by an entrepreneur with a strong interest in high-tech production techniques. This spirit is still with the company. The company consists of several departments including an in-house design department which is closely affiliated with the high-tech production facilities (also in-house).

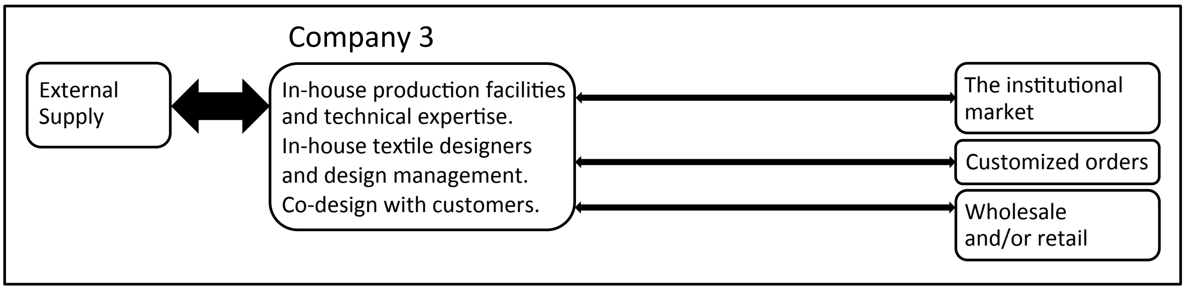

Figure 5: Company 3 has highly specialised in-house carpet production facilities; it relies primarily on in-house textile designers.

The C3 case is based on an existing report. Therefore it is difficult to provide a detailed discussion of the specific task partitioning and design activities that take place in the design and development process. We chose to include C3 as a case study in this paper, since it is one of the few companies still hosting in-house production facilities in Denmark. However, we are aware that basing our research on a report and not on actual interviews is a major constraint which has to be taken into consideration in future research.

Based on its advanced in-house design technology and process technology, C3 offers its customers a process of co-design, in the development of customised carpets. In this case, co-design means that the internal design team supports customers in their aesthetic and artistic design of the carpet. C3 also maintains a large collection of carpets to be delivered on demand with modifications wanted by the customer.

C3 has preserved and developed an in-house integrated design and production facility at the highest level of technology. The ability to co-design carpets in close collaboration with customers – and eventually freelance designers – with a short lead time is critical for the company's business model. The combination of design activities, design management, and production facilities enables C3 to offer several customized solutions to its customers. This is possible because the company has ownership control over the production facilities and at the same time has the design competencies in-house. The relationship to suppliers may be more transaction oriented, i.e. depending on current prices and qualities of yarn in the world market.

5.4 Company 4

Company 4 (C4) is a small knitware manufacturer mainly oriented towards the Danish/Scandinavian market. It is a family-owned enterprise (2nd generation) established in 1951. The company primarily consists of an in-house knitting mill, but also offers sewing and finishing services. C4 has built an expertise in flat knitting including jacquard techniques and various textures mastering these techniques to perfection. It has a small standard collection and also offers to produce customized knitware for clothing and interior accessories. C4 has specialized in the market for 'private label' collections. As such it provides production capacity for enterprises – retailers, manufacturers, designers etc. – operating in the market based on a label of its own. In the case of C4 the customers are typically small or medium-sized design-driven companies, e.g. independent designers.

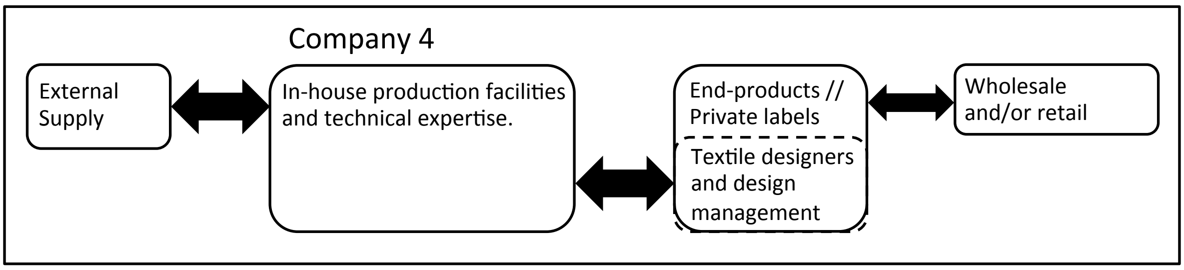

Figure 6: Company 4 primarily consists of an in-house knitting mill; it has specialised in the market for 'private labels'.

In C4 the owner takes responsibility for the collaboration with the customers. He is often involved in an intensive development process transferring the customers' design concepts into knitted products. The owner of the company has built a vast technical and material expertise over the years. He is capable of turning the design concepts and ideas into actual products. Thus, C4 adapts to the customers' requirements and spends little energy on market research and searching for new customers.

C4 offers specialized knowledge and production facilities to its customers. The traditional design processes are performed outside the company, which means that C4 is highly dependent on the customer's design knowledge and skills. Conversely the customer must rely on the technical expertise provided by C4.

This company may be seen as a local integrator delivering technical knowledge and production capacity to mainly Danish customers. What distinguishes C4 from the other companies in this study is that design and design management rest with the customer.

5.5 Company 5

Legend has it that the origins of Company 5 (C5) dates back to a Danish village weaver in the 1400s. The company was officially established in the 1750s. Originally it had its own production facilities, but today all production has been outsourced to manufacturers in Europe and the Far East. The company specializes in woven jacquard textiles for the high-end market of design and quality. C5 designs and sells household textiles (tablecloths, bed linen, towels etc.) mainly to retailers and from its web shop. In Denmark it has a number of flagship stores, while the products in other countries – primarily in Europe – are sold in individual shops specializing in household textiles or in department stores. C5 also fulfils customised orders. The company has extensive collaboration with (several) external designers and operates with a design and marketing management that coordinates the collaboration with the external designers.

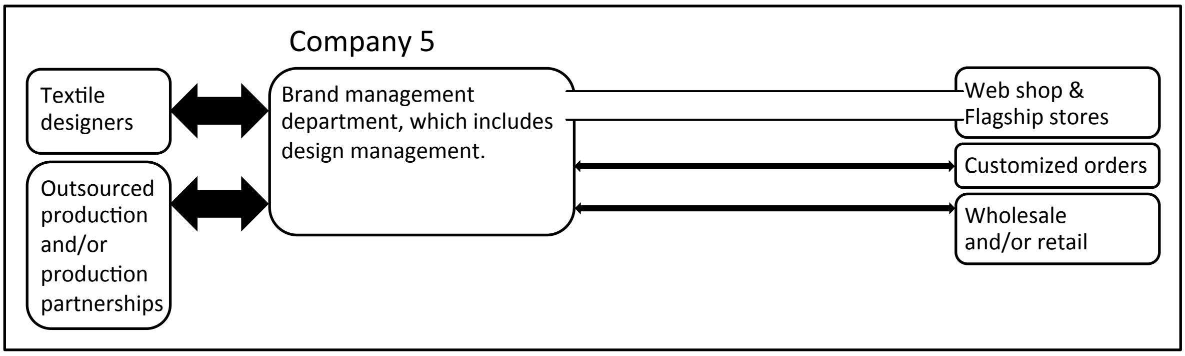

Figure 7: Company 5 primarily relies on external textile designers; it has its own web shop and flagship stores.

In C5 the design and marketing management is responsible for market surveillance and customer relationships. This includes contact to suppliers and production facilities. Usually new products are developed in close collaboration with an external designer; but C5 also uses some old, patented designs.

Usually external designers design C5's products. Among the designer's main responsibilities are ideation, aesthetics and colourways. Construction and contact to production sites and customers rest with the design management at C5.

C5 relies on the material and technological knowledge of its fabric manufacturers. The company has therefore developed a close, partnership-like relationship with these businesses. Knowledge exchange and mutual adaptation processes are important in the design driven business development of C5. As the figure indicate, tight control with the sales channels is also considered important in order to sustain the strong branding of C5. The company uses design management deliberately, and the task partitioning between designers and design management is clear.

5.6 Company 6

Company 6 (C6) was established in 1968 and is still managed by descendants of the founders (2nd generation). C6 is an internationally oriented enterprise designing and marketing for interior decoration (mainly fabric for furniture and curtains). The organisation of the company has never included in-house production facilities. Rather it relies on tight partnerships and relationships with a few preferred and highly specialized fabric manufacturers from all over the world.
The company has extensive collaboration with (several) external designers and has an in-house design department that manages the process of selecting and transforming the design concepts suggested by external designers into viable fabrics.

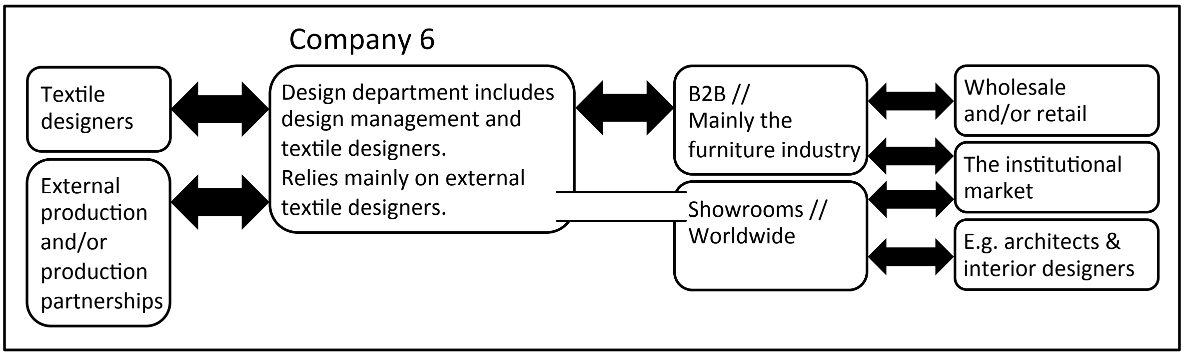

Figure 8: Company 6 has a strong in-house design management department, which has close collaboration with external textile designers.

In C6 the design management department holds a key position and has a highly competent staff with textile design expertise. The department supports and collaborates with external (textile) designers to develop initial ideas into viable design-based solutions. Strategically C6 aims to collaborate with 'flagship' designers as well as 'grass root' designers in order to track and benefit from actual trends. Obviously there are also designers who are responsible for maintaining the standard collection, new colourways etc.

External designers frequently design C6's products. The key role for these designers can be ideation, construction, aesthetics and colourways. However, the design responsibilities change in relation to the design task. The design management department in the company is responsible for contact to suppliers (fabric development and approving) and to customers (design), and for collaboration in-house. Another crucial responsibility is the collaboration with the external designers.

6. Similarities and differences in organisational networks

In this section we reflect on the first research question: 'How do design activities unfold under different organisational settings'? The case studies are summarised by comparing similarities and differences in their organisational network and relationships. We use the ARA model described above to summarise and compare the role of design activities, design management, production facilities and customers in the organisation and/or the organisation's network. The discussion represents the main characteristics of the companies – although we realize that reality is much more complex than shown here. However, we find it productive for further work to display these main characteristics of the organisations from a network perspective – acknowledging that further research will benefit from more detailed case analyses in order to be able to communicate the complexity of organisational networks and relationships within the textile industry in a thorough and exhaustive manner.

6.1 The Production facilities

C1, C2, C5 and C6 use only external manufacturers to produce their merchandise. C6 never owned production facilities, while C1, C2 and C5 started as textiles mills and have now outsourced their production facilities, turning design and marketing into core in-house activities. Two companies, C3 and C4, have production facilities in-house.

From an organisational network perspective the type and location of a production facility has a crucial impact on the design activities. In C1 and C2, which both have in-house design and design management, the design activities include close collaboration with the external manufacturer.
In C5 and C6, which basically work with external designers, the internal design management works closely with the external manufacturers, and the designer relies on the design management's communication of constraints and potentials.

C1, C2, C5 and C6 all have close relationships with their suppliers/manufacturers. The type of collaboration varies from relationships established and maintained over years to more formal partnerships. In comparison C3 and C4, which have their own production facilities, have a looser and more transaction-based relationship with their (yarn) suppliers. Reliable suppliers are a necessity, and most likely the companies try to use the same suppliers; but at the same time we find that they may move between suppliers in order to buy the best product (yarns) at the cheapest price.

6.2 The design activities

The design activities in C1, C2 and C3 are primarily based on in-house designers whereas C4, C5 and C6 mainly rely on collaborative partnering with external designers (note that C1, C3 and C6 work with in-house designers as well as external designers, but depending on the design activity still have their main focus on one or the other).

If we turn to the companies with in-house designers the design activities vary. In C1 and C2 the designers take part in the entire development process from market surveillance and ideation to product launch and marketing/sale. This means that they collaborate with many different actors in the company's network and take responsibilities beyond traditional textile design skills. The difference is that the designers in C1 design the fabric and /or textile solutions for furniture (office chairs), and even though they have close collaboration with their customers in the furniture industry they are not responsible for designing the end product. Designers in C2, on the other hand, design not only the fabric but also the textile end product for a specific market. In this light C1 and C2 take different positions in the value producing network and use and contribute to the organisational network in different ways. Design plays a crucial role positioning the company in its organisational network. C3 exemplifies a third type of design activities in an organisational network. The company has an in-house design department which maintains a standard collection as described in the case study; the in-house design department takes design orders from large customers (hotels, conference centres, airports, hospitals etc.), and the designers develop customized and 'one-off' carpets in close collaboration with the customer. C3 is to a greater extent than C1 and C2 a 'stand-alone' company even though it operates in an organisational network with suppliers and customers.

There are significant differences between the design activities related to C4, C5 and C6, which mainly work with external designers. C4 is basically a manufacturer and develops and manufactures based on requirements defined by the customers. In C4 the design activities are basically managed and controlled by the customer, whereas C5 and C6 control and manage the design activities. The difference between C5 and C6 is that C5 has a brand management department, which takes the responsibility of design management, and C6 has a strong in-house design management department, which includes key account designers. In C5 ideation and concept development are taken care of by external designers; in C6 on the other hand the external designers partly participate in the design development up until the fabric is ready for production and sale. In C6 the internal design activities and design management support the external design activities.

6.3 The Design management

All companies except C4 have in-house design management. This study indicates that design and hence design management has taken a stronger strategic role in business development in the textile industry. For the companies without in-house production it is crucial to have a strong in-house design management division in order to ensure that the suppliers fulfil the design requirements and the product lives up to the customer's expectations. In other words, design management is an important in-house activity that maintains the relationships with both manufacturer and customer. Design management as a liaison function matching material and process technologies embedded in the production network with needs and attractions articulated in the communities of customers and end-users.

For the companies with in-house designers the design manager often is the designer or works in the same department/has close collaboration with the designer/design department. For the companies without in-house designers the design management is responsible for a fruitful partnership with the designer and also maintains the relationship with both manufacturer and customer. The design management team communicates the design constraints inherent in both production opportunities and customer requirements to the designer.

For C4 design management is embedded with the customers. In the development process there is close collaboration between the customer's designer and/or design management and C4. Specifically the owner of C4 contributes with highly specialised knowledge about knitting technology and technical possibilities. The customer's designer/design management relies heavily on this expertise/these constraints to make decisions during the product development.

6.4 The Customers

All companies in this study have tight relationships with their customers. Yet the type of customer is very different and this is a way to differentiate between the companies. C2, C3, C4 and C5's products are end products, whereas C1's and C6's products are not.

C1's main customers are the furniture industry, which means that C1 basically is a supplier, since it does not develop or sell end products. The design activities are oriented towards the customers' needs and visions. C6 also has customers in the furniture industry and in that respect has the same orientation as C1. Additionally C6 has many customers among interior designers and architects, who buy the curtain fabric (and furniture upholstered with C6's fabric). C6 is a supplier in both cases, but has a different design and marketing strategy than C1.

C2's customers are basically leasing laundries, and the design activities are oriented towards the needs of the end market. C2 uses the design activities to create a link between the functional demands of the laundries and the emotional demands of their customers (who lease textiles at the laundries). C5's products are also adapted towards the end market, but the customers are of a different type. C5's main customers are the end users, which can be private and public institutions and individuals. In that respect C5 designs and sells primarily textile products to the end-users, whereas C2 focuses mainly on leasing laundries as its main customers.

It is more difficult to characterise C3's customers due to the broad product. According to the customized 'one-off' orders C3 benefits from in-house design activities and a design department that has the expertise to utilise C3's high-end production facilities to its full potential in order to meet the customer requirements. Even though the companies are very different C4 also benefits from high technical expertise. Both companies have a strong expert knowledge about their respective production facilities, and both companies are involved in the design activities due to their technical expertise.

7. Discussions and perspectives

In the previous section we have outlined ways in which design activities in an organisational network bring together a diversity of actors who draw on different resources. Each actor contributes with his or her professional qualifications, and in the organisational network they may be able to perform in a way that would be impossible if they adhered to the idea of organisations as closed entities. For example several of the cases in this study have shown that the designers' responsibilities are expanded to include not only traditional design work but also project/design management, market surveillance, customer contact etc. For example the designer can use his or her skills to combine technical opportunities provided by a supplier with an aesthetic/functional interest expressed by a customer. The supplier and customer may never have benefitted from mutual interaction if they had not been a part of that particular organisational network. And likewise the designer may never have had the opportunity to come up with the specific design solution if he or she was not an actor in the network.

In this section we will discuss the second research question: 'How does the role of design management change when design breaks through and crosses organisational boundaries'? This study is basically conducted as an exploratory study with the intension to study design activities and the role of design management spanning local Danish textile enterprises with global markets and production networks. However, the case studies point at several interesting perspectives in terms of design activities, which could be the basis for further research.

The first key issue we have identified concerns the design process. In an organisational network the traditional design process develops into what we suggest calling a distributed design process in which relationship management plays a crucial role. What characterizes a distributed design process in an organisational network is that it demands interdisciplinary and intercultural collaboration, since it takes place in a global network of suppliers, manufacturers, customers and end users. It also demands strong design management among the actors in the network.

Furthermore we have reason to believe that concrete design experiments taking place within an organisational network differ fundamentally from experiments taking place in-house between internal design and production departments. An advantage of working in an organisational network can be that opportunities emerge for combining knowledge in ways that differ from closed entities. It may imply that conceptual and technological knowledge can meet in a productive way. Disadvantages can be a lack in the spontaneity and fast exchange of knowledge between design and production that is possible when design and production are in close proximity in-house.

This means that the role of design changes from an internal capability serving in-house innovation to a collaborative capability enabling close collaboration and experimentation on product development in the business network that has been developed. Design has a key role of activating and combining knowledge and resources in the external network of suppliers to the benefit of the key customers and users served. Through the supply network the company gains access to resources and competencies that it might never have been able to establish in-house.

Finally we would like to contribute with the concept of key account design. To our knowledge key account design is not a well-defined term even though it seems that many organisations work with it. From our perspective it can be used to describe the often close relationship and collaboration between key account management and design. The role of the key account designer is to be an international bridge builder combining knowledge on new materials and technologies embedded in the supply network with needs and attractive visions embedded with the community of customers and users served locally or worldwide. A key to the innovative potential of the company is to extract value from the asymmetries existing in the global textile network. The demand is to develop and maintain a sustainable combination of tight and loose relationships with external enterprises. This in turn demands a strategic vision for the position to take, develop and defend in the network. Design has a crucial role to play facilitating collaborative innovation in the textile industry. At the same time design is a critical control parameter safeguarding the ability to extract value from the collaborative position taken.

In this light design management gains new momentum in the textile industry, since it seems to be a cornerstone in configuring innovative networks and facilitating co-designing across the traditional ownership-based limits of the company.

8. Concluding Remarks

In the introduction to this paper we posed two research questions: ‘How do design activities unfold under different organisational settings?’ and ‘How does the role of design management change when design breaks through and crosses organisational boundaries?’ We have used the case studies to explore what is going on in six organisations in the Danish textile industry and have thereby answered the research questions. As mentioned above this is by no means an exhaustive study of the textile industry. Still, we believe that it can indicate a trend in the industry moving from closed entities to open organisational networks.

The aim of this paper has been to add to the understanding of industrial textile design within a network perspective. We see this as an addition to Studd's study (Studd 2002). However, she represents the perspective of the traditional design activities within an organisation, whereas our purpose represents a network perspective of design activities. Therefore we found a need to explore how the design activities are extended/distributed and managed in organisational networks, and we chose to do this through six case studies.

Comparing the organisational networks we have discussed how design activities unfold under different organisational settings. As demonstrated, it is also crucial for the companies that rely on external production facilities to have a strong design management unit in order to maintain the relationships in their network of customers and suppliers. The character of the design management also depends on the presence / non-presence of internal design resources in the companies.

It is also relevant to take a look at Dicken's model presented above comparing it to the knowledge we generated about the core competencies of the companies that we studied. With only six case studies it is not fair to judge Dicken's model, but it is significant that the core competencies in the companies we studied are fundamentally different from the core competencies of the textile industry that Dicken shows in his model (yarn preparation and fabric manufacturing). In the companies we studied and also in general in the Danish textile industry (see Bang, 2010) the tendency is that the production is outsourced and therefore the core competencies have changed to a broader focus than traditional manufacturing. Several of the companies may describe this as a 'move forward in the value chain'. What we have tried to argue in this paper is the need to understand the companies as part of larger organisational networks rather than closed entities.

With this paper we laid out the framework for understanding the design and the design management that takes place within organisational networks of activities, actors and resources in the textile industry. We chose not to go into details about the actual textile design process. This is definitely a relevant subject, also in an organisational network perspective, but it is a subject in its own right and it deserves to be discussed in a separate paper.

Acknowledgements

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References

Albers, A. (2000). *Selected Writings on Design.* Middletown, CT: Wesleyan University Press.

Bang, A. (2010). *Emotional Value of Applied Textiles – Dialogue-oriented and participatory approaches to textile design.* PhD dissertation. Kolding School of Design, Denmark.

Bang, A. & Christensen, P. (2013). Co-creation in Distributed Value creation systems and networks. In: *Proceedings of the 10th EAD International Design Conference: Crafting the Future,* Gothenburg, Sweden 16-19 April, 2013.

Bang, A. & Christensen, P. (2011). Det skabende nærvær - co-design og relationsledelse som drivkraft i kreative virksomheder (in Danish), In: *CESFO Årsrapport*, pp. 7-13.

Center for Småvirksomhedsforskning, University of Southern Denmark.
Bjerregaard, T. & Christensen, P. R. (2008). In the Shadow of Public Hierarchies. Conceptualizing entrepreneurial strategies in local business development. In: *Proceedings of RENT XXII*, Covilhá, Portugal, 20-21 November 2008.
Dicken, P. (2003). *Global Shift – Reshaping the Global Economic Map in the 21st Century*. 4th edition. London: Sage Publications Ltd.
Dicken, P. (2011). *Global Shift – Mapping the Changing Contours of the World Economy*. 6th edition. London: Sage Publications Ltd.
Fiore, A. & Kimle, P. (1997). *Understanding Aesthetics for the Merchandising and Design Professional.* New York: Fairchild Publications.
Gale, C. & Kaur, J. (2002). *The Textile Book.* Oxford: Berg.
Håkansson, H. & Johanson, J. (1993). The network as a governance structure: interfirm cooperation beyond markets and hierarchies. In: Grabher, G. (ed.) (1993). *The Embedded Firm. On the Socioeconomics of Industrial Networks.* London: Routledge, pp. 35-51.
Håkansson, H. & Johanson, J. (1992). A Model of Industrial Networks. In: Axelsson, B. & Easton, G. (eds.) (1992). *Industrial Networks. A New View of Reality.* London: Routledge, pp. 28-34.
Håkansson, H. & I. Snehota (eds.) (1995). *Developing Relationships in Business Networks*, London: Routledge.
Håkansson, H., Ford, D., Gadde, L., Snehota, I. & Waluszewski, A. (2009). *Business in Networks.* West Sussex: John Wiley & Sons Ltd.
Studd, R. (2001). The Textile Design Process, *The Design Journal*, Volume 5:1, pp. 35-49.
Riisberg, V. (2006). *Design og production af trykte tekstiler – fra analoge til digitale processer* (in Danish). PhD Dissertation. Kolding School of Design, Denmark.
Wilson, J. (2001). *Handbook of Textile Design.* Cambridge: CRC Press.

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A modelling approach for Supply Chain planning and cash conversion cycle optimization based on scheduling theory

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Abstract

This paper addresses the implementation of financial cross-functional links with the supply chain operations at plant level when scheduling and budgeting in tactical and operational planning in batch industries. We propose a flow graph modelling approach based on shop scheduling theory which approach permits to model operational logistic activities including cash flow management. Modelling supply chain as a shop scheduling model defines a scheduling problem which consists in scheduling a set of batches that have to be sequenced on *m* plants. Each batch involves a set of plant-operations, which must be processed in a predetermined order. This work is a step forward definition of modelling approach for supply chain management including both scheduling and cash flow constraints. The proposed modelling approach is presented and justified.

Keywords: Supply chain, cash conversion cycle, job-shop, scheduling, disjunctive graph

1 Introduction

In today's rapidly changing economic and political conditions, firms can't compete solely and need to construct a Supply chain (SC) with its suppliers and distributors. There are many examples of the benefits of coordination activities to the individual members in the supply chain (Vickery et al. 2003). Supply chain integration is defined overall as a process of redefining and connecting entities through coordinating or sharing information and resources (Katunzi, 2011). Supplier integration suggests that suppliers are providing information and directly participating in decision making (Petersen et al., 2005). It is characterized by a cooperative relationship between the buyer and the upstream supplier. Often these relationships incorporate initiatives and programs that foster and strengthen the linkages between buyer and supplier (Vijayasarathy, 2010).

1.1 Supply chain

Supply chain can be defined as a system of logistic units which can be suppliers, manufacturers, distributors, retailers and customers where material, financial and information flows connect participants in both directions. In this paper we consider an external integrated supply chain composed by individual firms. Therefore, a supply chain may be defined as a coalition of autonomous actors coordinated thanks to an integrated logistic process. Each actor crossed by logistic process is seen as an autonomous logistic unit of the supply chain which unit sells and buys items with a negotiated price. Figure 1 shows such SC where material and financial flows are highlighted. This chain is characterized by forward flow of materials and backward flow of cash. A series of cash flows occurs over time in two forms.

Accounts Payable or Cash outflows include expenditures for labours, equipment and materials required to achieve each logistic activity. Accounts receivable or Cash inflows are induced by progressive payment for completed work or product. As stressed by Fiala (2005) supply chain management is now seen as a governing element in strategy and as an effective way of creating value for customers. On the other hands cash is a vital resource needed to support almost all activities in the SC. It provides a cushion for companies during difficult times, and allows them to swiftly take advantage of growth opportunities by expansion (Tsai, 2008).

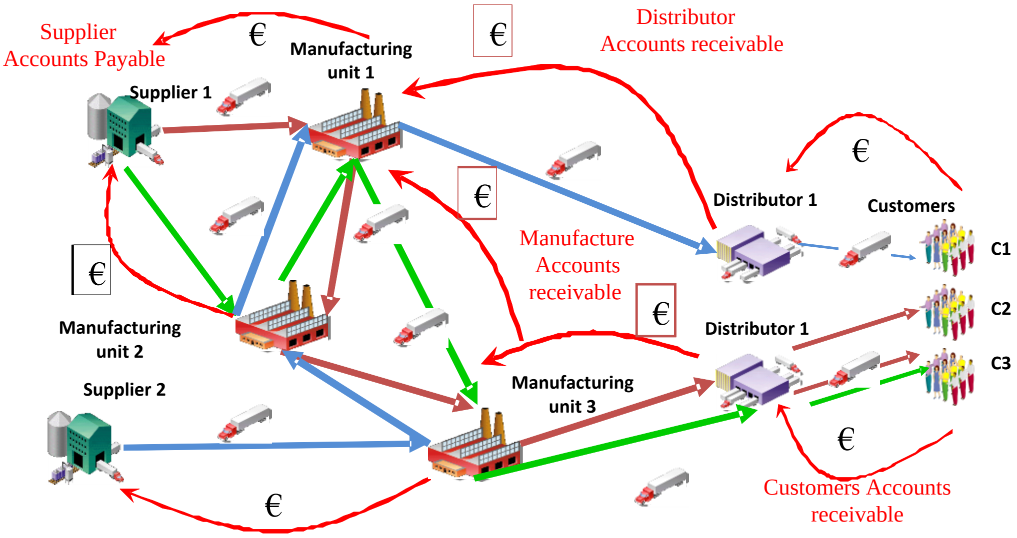


Figure 1. Supply chain of goods and cash for all members.

The logistic process, which integrates all actors, is composed of logistic activities realized by different logistic units. Figure 3 summarizes and presents a logistic activity. This activity is realized by a logistic unit which can be any one of SC members: suppliers, manufacturers, distributors or retailers. To start the activity raw materials or goods should be purchased by the suppliers using payment which patterns are negotiated by the supply chain members (logistic units). According to the Figure 2, a logistic activity has a lead time (duration) composed of waiting time in inventory before processing, of time in work-in-progress (WIP) during operational processing, waiting time in inventory after processing (waiting for transport) and time in transport.

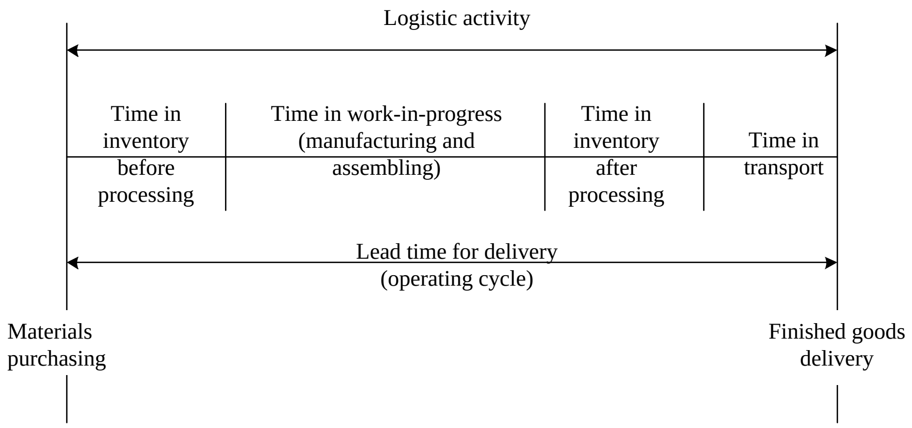


Figure 2. Logistic activity description.

1.2 Cash conversion cycle

The Cash Conversion Cycle (CCC) (Jose al., 1996) also known as the Cash-to-Cash Cycle is heavily dependent on a company's supply chain capability. CCC is a measure of cash turnover of SC with respect to three supply chain activities, purchase, internal operations, and sales. In fact, the CCC measures the time between cash outlays for materials and cash receipts from product sales. The CCC combines both balance sheet and income statement data to create a measure with a time dimension. Figure 3 provides an illustration of the CCC in terms of relation of relationships between accounts payable, accounts receivable, inventory management and logistic activity. It contains three elements: *(i)* days in inventory, *(ii)* days in receivables (cash inflow), and *(iii)* days in payables (cash outflow). These three elements vary across industries and may depend on the market power of the organization with respect to its customers and suppliers. These three time-related factors are affected by the planning and scheduling of logistic activities, credit periods of receivables and payables.

Shorter CCC means lower financial costs to fund business operations (Tsai, 2008). To reduce the CCC, a company can reduce days-in-inventory, shorten days-in-receivables and prolong days-in-payables. From the cash flow point of view, the CCC is one of the popular supply chain performance measures (Farris II and Hutchison, 2002).

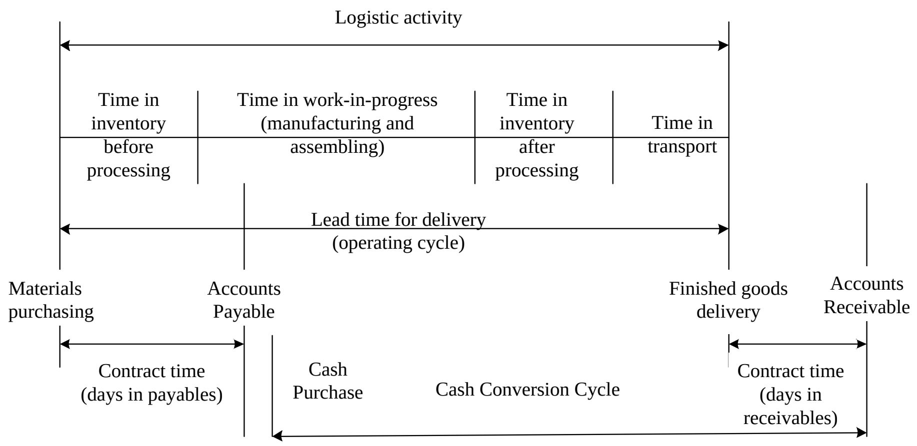


Figure 3. The cash conversion cycle and logistic activity.

Cash management is concerned with optimizing the short term funding requirements of a company and as such is a financial activity of importance to the treasuries of companies operating in either a national or international environment (Gormley and Meade, 2007).

Since in the SC the number of row materials, of WIP products and of finished goods present simultaneously into the system is limited and the processing times are constant, the only way to minimize the lead time and by this way the CCC is to reduce the waiting times due to the blocking and non-availability of resources needed. Therefore, the objective is to find such planning which best satisfies the following objectives: (i) to reduce the cumulative lead time of the production schedule; (ii) to improve the machine utilization.

Since operational planning in scheduling has the same horizon term as cash management planning (Stadtler, 2005), to improve cash flow performance, financial considerations must be taken into account during the planning, scheduling and control of logistic activities avoiding costly solutions due to excessive credit allocation preventing bank overdraft. A better synchronization of material and financial flows avoiding day-to-day negative cash flow leads to integration of SC performance and financial measures which integration is critical to both supply chain and financial managers.

In order to achieve organize the synchronization of material and financial flows and better define their activities, firms implement a lot of management actions based on planning processes. These are divided into three distinct levels according to the length of the horizon plan under consideration (see Anthony 1965, Fleischmann *et al.* 2002, Bertrand 2003):

- Long-term planning (e.g. 3–5 years): decisions of this level are called "strategic decisions" and cover a wide scope of supply parameters including capacity sizing, entities location, product families' allocation and product portfolio definition. Consequently, they constitute a crucial task whose impact on system under consideration is measurable during many years (Simchi-Levi *et al.* 2004). So a good strategic decision process gives to firm bases to compete with challengers in the future but doesn't guarantee success whereas unsuitable strategic decisions lead inevitably to future economic difficulties;
- Mid-term planning (e.g. 6-24 months): within the scope of strategic decisions, mid-term or tactical planning determines an outline of the regular operations, in particular rough quantities and times for the flows and resources enabling the consideration of seasonal trend of demand. Tactical problem types attempt to adopt the most optimum use of the various resources, including manufacturing plants, warehouses, transports etc.

- Short-term planning (e.g. from 1-3 months): the lowest planning level or operational level has to specify all activities as detailed schedule for immediate execution and control. The variable of time is introduced, correlating the determination of the number of logistic facilities, geographical locations, and capacity of facilities to the optimal daily allocation of customer demand to retailers, DCs, and/or production plants. Operational problems are related to the detailed scheduling definition, sequencing, lot size, assigning loads and vehicle routes etc.

This paper concerns the tactical and operational planning. Here, we propose a modeling approach based on scheduling theory (Pinedo, 2012) which approach permits to model operational logistic activities including the inflow and outflow delays and days-in-inventory.

The next section provides a brief literature review followed by an introduction of the assumptions used in this study in Section 3. This section includes also the modelling approach presentation. Next section illustrates our approach using a case study. The key findings of this study and conclusions drawn are presented in Section 5.

2 Related work

Inclusion of cash flow in scheduling problem has been studied with different objective value which leads to the Resource Investment Problem (RIP) (Najafi al., 2006) and the Payment Scheduling Problem (PSP) (Ulusoy G. and Cebelli, 2000). These approaches are based on cash flows in networks structure, defined by (Russel, 1970; Russel, 1986)). Depending on the objective, publications encompass both net present value (Elmaghraby and Herroelen, 1990) and extra restrictions as bonus-penalty structure (Russel, 1986; Zhengwen and Xu, 2008)), or discounted cash-flows (Najafi al., 2006; Icmeli, 1996)).

Using an activity based costing (ABC) system to bridge between supply chain physical and cash flows, Comelli et al. (2008) proposed a tactical production planning model, which permitted users to assign weights among value creation, cash flow, and potential of value creation on an evaluation function. It is a very comprehensive and flexible model but requires an ABC system in place.

Tsai (2008) studied the influence of trade terms under a stochastic demand process on cash flow risks and showed that using trade discounts to encourage early payment by customers increased cash inflow risk despite an improved cash cycle. Tsai (2011) studies the relationship between physical and cash flows, during a growth period without imposing any constraints. A stochastic optimization model is then developed to observe the managerial implications of cash flow risk under tight cash constraints.

Very few works propose to analyze cash flow and scheduling problem as an operational problem of cash management. The main objective of cash manager is to have enough cash to cover day-to-day operating expenses.

Cash management problem was simply formulated by (Baumol, 1952) as an inventory problem assuming uncertainty (Miller and Orr, 1966). Two types of metrics are generally used to optimize financial flow: cash position which reveals the cash which is available at the end of a specific period and cash flow which reveals cash generation during a specific period. In a recent paper, (Badell et al., 2005) optimizes financial flow and cash position in the end of each period. This kind of approach does not take into account the reverse logistic problem (Guide and Wassenhove, 2002). Forecasting a budget or the cash position consists in linking together financial and physical flows. (Bertel et al., 2008, Comelli et al., 2008) shows the links between financial and physical flows in an operational way, but the proposed approach deals with a supply chain which is modeled as a flow shop. (Vickery et al., 2005) holds that combined financial and production-distribution models should be considered in the area of Supply Chain Management in operational level but that the proposed works deal with firm problems, not logistic problems.

As previously stressed, there is a lack of decisional tools for supply chain optimization at the operational level taking simultaneously financial constraints and scheduling ones. Moreover, after a literature review, Elazouni and Gab-Allah (2007) show that “available scheduling techniques produce financially non-realistic schedules”.

The job-shop problem consists in finding a feasible schedule with minimal *makespan* (minimal global duration). The job-shop problem has received a considerable amount of attention over the years, with numerous extensions including but not limited to transportation constraints, time-lags constraints, due dates and non delay execution of operations….

Recently Féniès et.al., (2010), Kemmoe et al., (2011a) and Kemmoe et al., (2011b) formulated the problem so called “job-shop with financial constraint” (*JSFC*) which is defined as a job-shop problem with simultaneously consideration of manufacturing specific resource requirements and financial constraints. Tackling financial considerations permits to consider the proper coordination of production units when optimizing the supply chain. The main goal is to obtain the smallest duration of a given supply chain operational planning which planning respects the budget limit of each production unit. In order to understand the physical and financial exchanges between the different production units Kemmoe et al., (2011a) proposed a linear program. A linear program is useful to obtain optimal solutions on small and medium industrial instances. However, the model does not consider delays of payments. Later Kemmoe et al., (2012) extended Kemmoe et al., (2011a) linear program to take into account the terms of payments. Using a decomposition approach logistic activities are modelled to consider delays of cash outflows and cash inflows.

3 Modelling supply chain physical and cash flows

Basic assumptions adopted in this study are outlined in the section. We consider the problem from the viewpoint of a supply chain member who receives finished products from several up-stream partners and then distributes these products to several downstream partners.

3.1 Supply chain statement and assumptions

Modelling a supply chain as a job-shop (Figure 3) allows taking into account phenomena such as reverse logistics. The fact that integrating financial flows allows to extend financial constraints on physical flows. One of the challenging problems in supply chain management consists in coordinating production units and financial considerations properly. The main origins of costs in supply chains are capacity and material costs which must be carefully coordinated. Typically scheduling decisions are made in the short term (several weeks or months) and financial decisions follow to satisfy the required base-stock levels and human resources. Operational planning in scheduling (Stadtler, 2005) has the same horizon term as cash management planning. The second-level financial decisions are constrained to accommodate previous scheduling solutions.

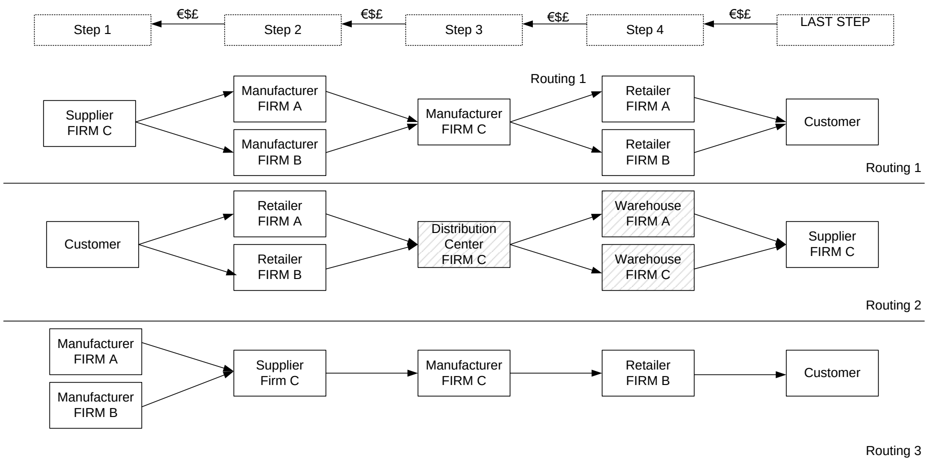


Figure 3. Modeling supply chain as a job-shop.

The current trend of companies is to launch customer demands as early as possible and to propose a delivery time satisfying the customer's required due date. In order to control the work in process, financial considerations must be taken into account avoiding costly solutions due to an excessive credit allocation preventing bank overdraft. A series of cash flows occurs over time in two forms. Cash outflows include expenditures for labours, equipment and materials required to achieve one operation. Cash inflows are induced by progressive payment for completed work or job.

From a scheduling point of view the objective is delivering jobs according to due dates and warehouses' capacity. From a financial point of view, the aims depend on strategic or tactic considerations including the net present value or the cash flow. Gunasekaran and Ngai (Gunasekaran and Ngai, 2004) have proposed a review on metrics for evaluating chain performance and distinguishing between financial and non-financial metrics. Expected benefits of supply chain management with financial evaluation / optimization commonly include but are not limited to:

- Throughput improvements by correct material and capacity coordination;

- Cycle time reduction by considering constraints as well as its alternatives;
- Inventory cost reductions by a lowest requirement of inventory levels against uncertainty.
- Ability to know when to buy materials based on the customer demand and logistics capacity;
- Optimized transportation by optimizing logistics and vehicles loads.

3.1.1 Physical flow assumption

We consider the cash flow of a manufacturer who purchases materials from suppliers, turn them into semi-finished or finished goods and sell to distributors on a make-to-stock basis. Trade between any two parties is based on credit sales with stated credit terms. The manufacturer receives money from the downstream partners and makes payments to the up-stream partners. For tractability purposes, here we are assuming that the future cash inflows from downstream partners and future outflows along with their terms from up-stream partners are known.

To better understand this relationship we propose to model a given supply chain (Figure 1) as shown on Figure 4, where each product has its own process plan which defines the product routing trough the supply chain. Therefore the product will be treated successively by a supplier unit, manufacturing units and distributor.

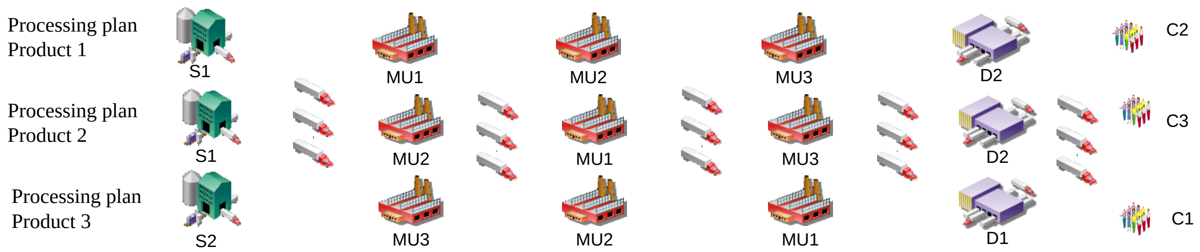
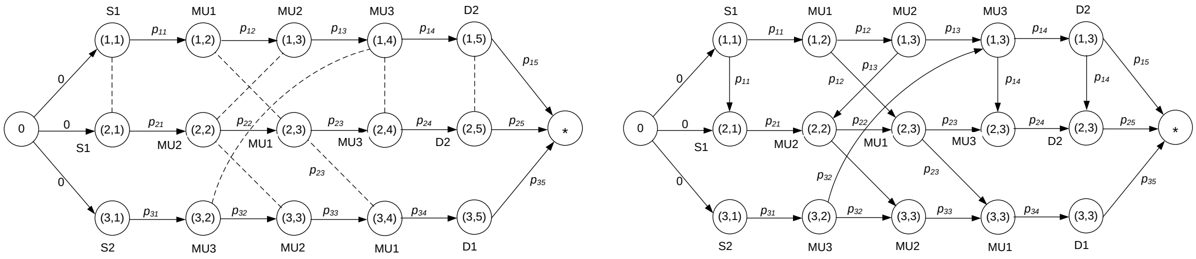


Figure 4. Product processing plans through the supply chain.

This supply chain model permits to address the proper coordination between material lots (jobs) and financial considerations. Our approach is based on the job-shop theoretical model (Kemmoe et al., 2011a; 2011b). The deterministic job-shop scheduling problem, hereinafter referred to as *JS*, is the most general of the classical scheduling problems.

The *JS* consists of a finite set J of n jobs $\{J_i\}_{i=1}^{k}$ to be processed on a finite set M of m machines $\{M_k\}_{k=1}^{m}$: Each job J_i must be processed on every machine μ_j during a processing time $p_{i,j}$ and consists of a chain or a set of O operations $O_{i,1};O_{i,2}; . ;O_{i,\mu j}$, which have to be scheduled in a predetermined given order (precedence constraint) and no preemption is allowed. The *JS* problem consists in finding a feasible schedule with minimal makespan (minimal global duration) C^{max} by a careful management of machine disjunctions. The job-shop problem has received a considerable amount of attention over the years, with numerous extensions including but not limited to transportation constraints, time-lags constraints.

Using the disjunctive graph (Roy and Sussmann, 1964) the logistic activities can be modelled by a vertex. Precedence constraints between operations are represented by an arc. Disjunctive constraints between two operations (logistic activities) which require the same machine (logistic unit) are modelled by an edge. An arc has a total cost equal to the duration of the beginning operation. The corresponding non oriented and oriented disjunctive graphs of the SC problem of Figures 1 and 4 are presented on Figure 5.



Non oriented disjunctive graph Oriented disjunctive graph

Figure5. Oriented disjunctive graph $G(\lambda)$ representing a solution of SC scheduling, p_{ij} is the processing time of logistic activity *j* of job (batch) *i* including transport time.

The arcs between machine operations which use the same machine define the machine operations sequences. The oriented disjunctive graph of Figure 5 represents a solution in which on machine 1 (S1) the sequence is: operations $O_{1,1}, O_{2,1}$; on machine 2 (S2) the sequence is: $O_{3,1}$; on machine 3 (MU1) the sequence is: $O_{1,2}, O_{2,3}, O_{3,3}$; on machine 4 (MU2) the sequence is: $O_{1,3}, O_{2,2}, O_{3,3}$; on machine 5 (MU3) the sequence is: $O_{3,2}, O_{1,3}, O_{2,3}$; on machine 6 (D2) the sequence is: $O_{1,3}, O_{2,3}$ and the sequence on machine 7 (D1) is $O_{3,3}$. Since the transport resources are not considered (there are enough) the transport times are included in processing time. The problem consists in defining an orientation of the graph $G(\lambda)$ minimizing the makespan ($C^{\max}$)and avoiding inconsistent graphs generation.

3.2 Financial flow assumptions

3.2.1 Financial outflow assumptions

The cash outflow assumptions are as follows:

- We assume that there is no purchase lead time. All materials need to arrive before the production starts depending on the process plan. For example, materials for producing batch *i* need to arrive in period k for the production to begin in $k+1$.
- The manufacturing unit and distributor unit always pay its suppliers (supplier or manufacturing unit) at the maturity of its accounts payable (AP), which has a given credit term.

3.2.2 Financial inflow assumptions

The cash inflow assumptions are as follows:

- Sales/shipments occur at the end of each processing time.
- There is a given credit term offered to customers (manufacturing unit or distributor).

Using the assumptions described above and the hypothesis that each logistic activity has duration which can be composed of different delays for example see Figure 5) To fully define Cash flows assumptions the following additional notations are used (Figure 5):

α_i : delay for the supplier to receive financial amount for delivering the resource necessary to execute logistic activities of batch *i;*

a_i : account receivable (financial resource) generated by logistic activity j (inflow) for batch *i;*

$s_{i,j}$: starting time of activity *j* of batch *i*;

$c_{i,j}$: completion time of activity *j* of batch *i*;

β_i : delay between the finish time of logistic activity j on batch *i* and the time of account receivable a_i ;

$p_{i,j}$: is the processing time of batch *i* by logistic activity j;

f_i : accounts payable (financial resource) required to pay the supplier of the logistic activity *j* of batch *i*;

$\varphi_{l,m}$: denotes the number of financial units (financial flow) directly transferred from activity m to l.

φ_j : denotes the number of financial units purchased by business unit realizing activity *i*

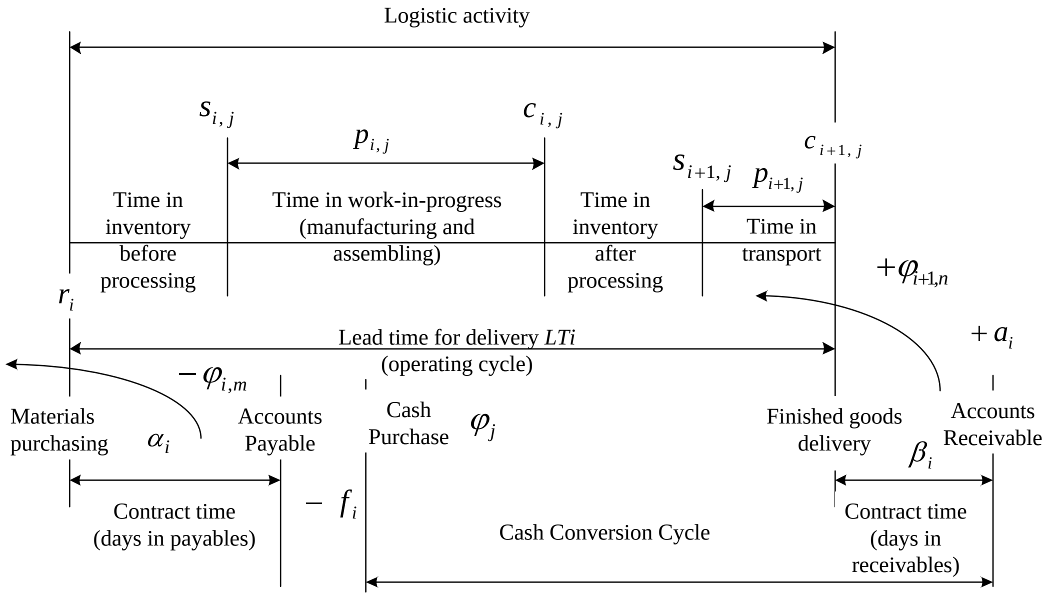


Figure 5. The cash conversion cycle, logistic activity and notation.

Depending on the terms of payment and ratio to the logistic activity processing time there are different possible combinations between the supplier's delays and the processing time of the logistic activity. These combinations are presented below.

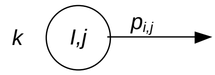
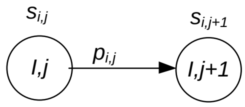
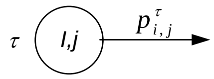
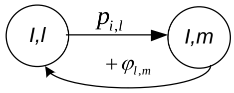
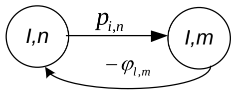
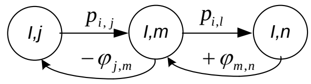
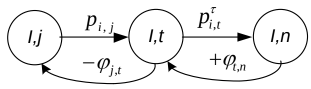
The cash inflow and outflow constraints complying with oriented disjunctive graph $G(\lambda)$ can be addressed by a flow network $G^{FN}(\lambda)$. The network flow has important features that are operated in a complementary manner to model the financial constraints (financial resource generated by machine operation and financial resource required by machine operation).

A solution of the problem consists in computing a multiflow φ^{λ} complying with the minimal and maximal cash flow constraints on the arcs. Finding a flow $\varphi_{l,m}$ in a graph is not straightforward and could be time consuming. Kemmoe et al. (2013) presented an efficient approach to solve simultaneously the job-shop with financial constraints problem.

3.3 Rules for SC and CCC modelling

To conclude this section, Table 1 proposes a synthesis which explain how modelling each generic activity of the supply chain, and its impact on the financial flow.

Table 1. Synthesis.

Supply chain activity	Job shop translation rule	Mathematical formulation	Graph modelling
Working process of batch *i*	Operation *j* done on machine *k* for job *i*	$p_{i,j}^{k}$	
Storage of batch *i*	Delay between completion time of operation *j* and starting time of operation *j+1*	$Inv_i = s_{i,j+1} - (s_{i,j} + p_{i,j})$	
Transport process of batch *i*	Operation *j* done on machine τ for the transport job *i*	$p_{i,j}^{\tau}$	
Cash inflows	Arc between nodes modelling logistic activities *m* and *l* of job *i*	$+\varphi_{l,m}$	
Cash outflows	Arc between nodes modelling logistic activities *m* and *n* of job *i*	$-\varphi_{m,n}$	
Cash outflows — Working process — Cash inflows	Arcs between nodes modelling logistic activities *j*, *m* and *n* of job *i*	$-\varphi_{j,m}$, $+\varphi_{m,n}$	
Cash outflows — Transport process — Cash inflows	Arcs between nodes modelling logistic activities *j*, *t* and *n* of job *i*	$-\varphi_{j,t}, +\varphi_{t,n}$	

Using notations presented above the *CCC* can be expressed as:

$$CCC = \frac{\sum_i^k Inv_i}{(COGS / C^{\max})} + \frac{\sum_{l,m}^{K,M}\left(+\varphi_{l,m}\right)}{(\sum_{l,m}^{K,M}\left(+\varphi_{l,m}\right) / C^{\max})} + \frac{\sum_{n,m}^{K,M}\left(-\varphi_{n,m}\right)}{(COGS / C^{\max})}$$

where *Inv* and *COGS* are average inventory and Cost of Goods Sold respectively during the scheduling horizon C^{max}.

4 Numerical example

4.1 Data

For tractability purposes we choose a small example from Kemmoe et al., 2012. The case study consists of a batch specialty multiproduct supply chain (taken out from a real industrial scenario) with two different batch manufacture logistic units *MLU 1* and *MLU 2*. Each batch processing plan basically consists of the two logistic (manufacturing) activities (Table 2). Raw materials and semi-finished goods are purchased by two suppliers. For the second product operation each *MLU* has two suppliers: the first one the precedent *MLU* depending on the processing plan and the second one of two suppliers. After each first product operation part of the batch is sold to customers. At the beginning of the scheduling horizon each manufacturing logistic unit has each own available cash of 40 units. Tables 3 – 4 give terms of payment:

- delays of accounts payable (supplier or *MLU*) for each logistic activity α_i;
- amount of the account payable $f_{i,j}$;
- amount of the account receivable $a_{i,j}$.

Table 2. Manufacturing processing plans.

Product	Logistic unit	Processing time	Logistic unit	Processing time
Product 1	*MLU 2*	21	*MLU 1*	53
Product 2	*MLU 1*	21	*MLU 2*	50
Product 3	*MLU 1*	39	*MLU 2*	98

Table 3. Amount and delays after procurement of account payable for each supplier.

Logistic Activity	Product	Supplier 1		Supplier 2		Supplier MLU 1		Supplier MLU 2	
		Amount	Delay α_1	Amount	Delay α_2	Amount	Delay α_3	Amount	Delay α_4
1	1	2	2	20	2	-	-	-	-
2	1	5	5	-	-	-	-	3	3
3	2	2	2	12	1	-	-	-	-
4	2	51	15			2	2		
5	3	3	3	34	3	-	-	-	-
6	3	9	9			8	8		

Table 4. Amount and delays after shipping of account receivable for each MLU.

Logistic Activity	Account receivable $a_{i,j}$	Delay $\beta_{i,j}$
1	12	1
2	15	3
3	32	40
4	35	3
5	52	1
6	55	3

4.2 Results

Using problem data the supply chain operational planning problem is modeled as a job-shop problem. The non-oriented disjunctive graph of the job-shop problem without financial constraints is given in Figure 6. In the Figure 6 the dotted edges are machine disjunctions.

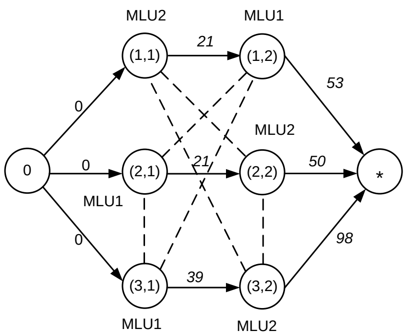


Figure 6. Non oriented disjunctive graph defining the problem as a job-shop.

Using a linear programming (Kemmoe et al., 2012) the problem is solved. Figure 7 shows the disjunctive graph of the optimal solution. The bold arcs form the critical path. The duration of each machine disjunction arc takes into account the terms of payment and cash flow position of each *MLU*. The arcs in bold model are the critical path. For example the duration of the dotted arc on the critical path between activities (3,2) and (2,2) is equal to 101 which value is the sum of the processing time of activity (3,2) 92 and the delay of account receivable (cash inflow) equal to 3. Gant chart of optimal solution is given in Figure 8

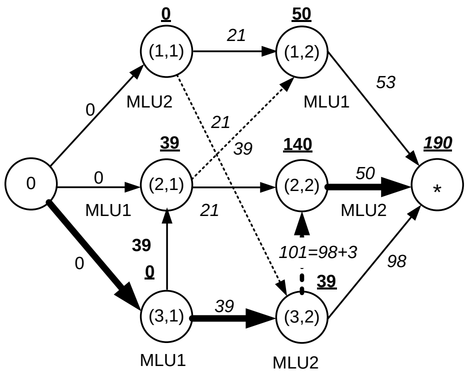


Figure 7. Fully oriented disjunctive graph of the optimal solution, makespan C^{max} is equal to 190.

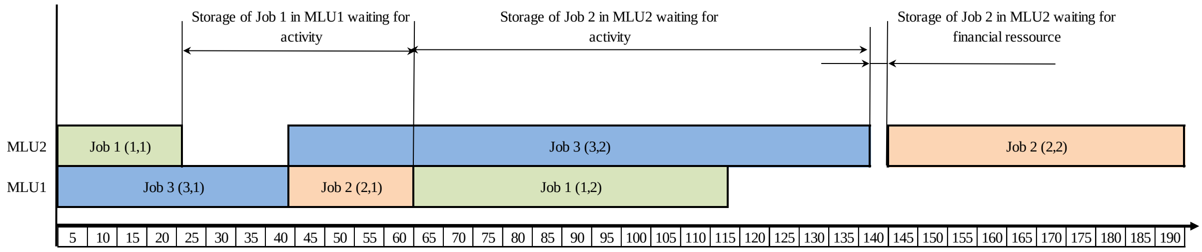


Figure 8. Gantt chart of the optimal schedule with financial constraints C^{max} is equal to 190.

Figure 9 gives the Gantt chart of Job 2 processing and the schedule of financial transactions. Using definitions presented above Figure 9 details different elements which composed the *CCC* like inventory, operating cycle, accounts payables and receivables. The Figure 9 provides an insightful look at supply chain cash flow. It describes the behavior of cash flow with respect to trade terms and processing lead time related factors.

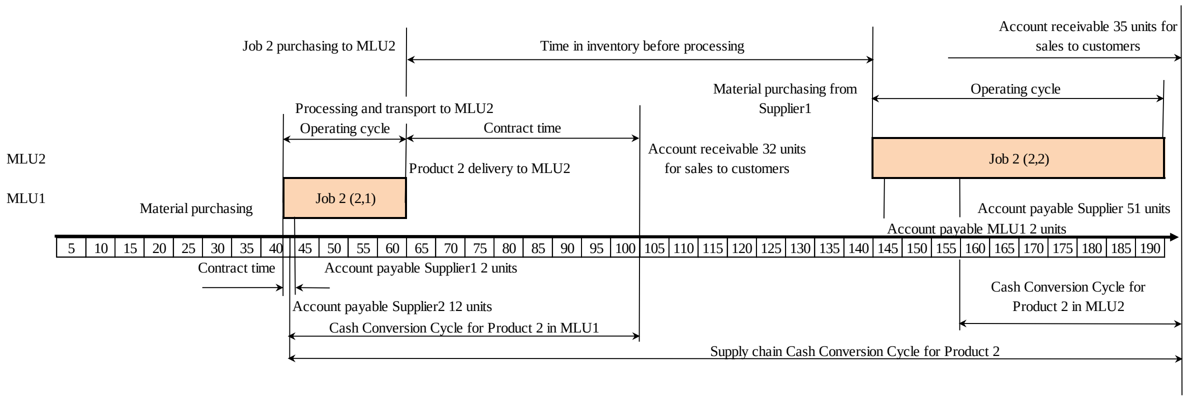


Figure 9. Gantt chart of the Job 2 (product 2) processing and the corresponding *CCC*

Table 5. Amount transfer results for the activities, solution of the flow network $G^{FN}(\lambda)$.

Origin activity	Destination activity	Amount of financial unit transfer
0	(1,2)	2
0	(2,1)	1
0	(3,1)	37
0	(1,2)	22
0	(2,2)	2
0	(3,2)	8
0	(3,2)	8
(3,1)	(1,2)	3
(3,1)	(1,2)	3
(3,1)	(2,1)	1
(3,2)	(2,2)	51
(1,2)	(3,2)	1

In table 5 the transfers between sub-activities of the same *MLU* are given: for example the transfer from activity (3,1) to activity (1,2) which activities belong to *MLU1*. The transfer from dummy origin node to any activity represents the initial financial resource consumption. For example the amount of transfer from 0 to activities (2,2), (2,1), (3,1) is equal to 40 (2+1+37) which is the amount of initial available cash for MLU1.

5 Conclusion

This article addresses the problem of scheduling in job-shop with financial consideration i.e. to schedule the operations efficiently while respecting the financial capacity of a supply chain. Here, is proposed a modeling approach based on scheduling theory which approach permits to model operational logistic activities including the inflow and outflow delays and days-in-inventory. This paper addresses the implementation of financial cross-functional links with the supply chain operations at plant level when scheduling and budgeting in tactical and operational planning in batch industries. Based on the shop scheduling theoretical models like job-shop the proposed approach is a step forward definition of wide-ranging methods for shop problem. The key features of this current study are to define supply chain model with financial constraint for simultaneously addressing during optimization:

- physical metrics (makespan);
- financial metrics (cash position, cash flow, *CCC*);

The supply chain model permits the use of high efficiency optimization algorithms to obtain trade-off solutions during the routine practice preserving at most the profit and liquidity while satisfying customers.

Our research will be directed into the definition of GRASP-ELS framework taking advantages of all previous remarks and propositions. The GRASP-ELS is a combination of the GRASP metaheuristic and the ELS metaheuristic combining the positive features of both methods. The GRASP (Greedy Randomized Adaptive Search Procedure) is a multi-start local search metaheuristic. At each iteration, an initial solution is constructed using a well-known job-shop heuristics. It is then improved by a local search and the best solution obtained at the end of each GRASP iteration is kept. The Evolutionary Local Search (ELS) is an extension of the Iterated Local Search (ILS). At each iteration of the ELS, several copies of the current solution are done. Each copy is modified (mutation) before being improved by a local search. The best obtained solution is kept as the new current solution. The purpose of the ELS is to better investigate the neighbourhood of the current local optimum before leaving it, while the GRASP aims at managing the diversity during the solution space exploration. The framework we promote is a multi-start ELS in which an ELS is applied to the initial solutions generated by greedy randomized heuristics.

References

Anthony, R.N. (1965). *Planning and Control Systems*, A Framework of Analysis, Boston.

Badell, M., Romero, J. and Puigjaner, L. (2005). Optimal budget and cash flows during retrofitting periods in batch chemical process *industries, International Journal of Production Economics* 95, 359–372.

Baumol W. J., (1952). The transaction demand for cash: an inventory approach, *The Quarterly journal of economics* 66, 545-556.

Bertel, S., Féniès, P. and Roux, O. (2008). Optimal cash flow and operational planning in a company supply chain, *International Journal of Computer Integrated Manufacturing* 21/4, 440-454.

Bertrand, J.W.M. (2003). Supply Chain Design: Flexi-bility Considerations, de Kok A.G., Graves, S.C., (Eds). Handbooks in OR & MS, 11, chapter 4.

Comelli M., Féniès P. and Tchernev, N. (2008). Combined financial and physical flows evaluation for logistic process and tactical production planning: Application in a company supply chain, International Journal of Production Economics 112/1, 77-95.

Elasouni A.M. and Metwally, F.G. (2007). Expanding Finance-Based Scheduling to devise Overall-Optimized Project Schedules, *Journal of Construction Engineering and Management* 133/1, 86-90.

Elmaghraby A.E. and Herroelen, W.S. (1990). The scheduling of activities to maximize the net present value of project, *European Journal of Operational Research* 49, 35-49.

Fleischmann, B., Meyr, H., Wagner, M. (2002). Advanced Planning, in Supply chain management and advanced planning, Stadtler, H., Kilger, C., (Eds), chapter 4, Berlin, Springer Verlag.

Farris II, M.T. and Hutchison, P.D. (2002). Cash-to-cash: the new supply chain management metric, International Journal of Physical Distribution & Logistics Management 32/4, 288–298.

Féniès, P., Lacomme, P., Toussaint, H. and Quilliot, A. (2010). Supply chain optimization with negative cash flow optimization during planning", *12th LSS Symposium, Large Scale Systems Theory and Applications*, Villeneuve d'Acsq (FRANCE), 12-14 July 2010.

Fiala, P., (2005). Information sharing in supply chains, Omega: The International Journal of Management Science 33, 419–423.

Gormley, F. M. and Meade, N. (2007). The utility of cash flow forecasts in the management of corporate cash balances, European Journal of Operational Research 182, 923–935

Guide V.D.R and Wassenhove L.N. (2002). The reverse Supply Chain, *Harvard Business Review* 80/2, 25-26.

Gunasekaran A., Ngai E.W.T. (2004). Information systems in supply chain integration and management, *European Journal of Operational Research*, 159/2, 269-295.

Jose, M.L., Lancaster, C., and Stevens, J.L. (1996). Corporate returns and cash conversion cycles, Journal of Economics and Finance 20 (1), 33–46.

Icmeli O. and Erenguc S.S. (1996). The resource constrained time/cost tradeoff project scheduling problem with discounted cash flow, *Journal of Operations Management* 14, 255-275.

Katunzi, T.M., (2011), Obstacles to process integration along the supply chain: manufacturing firm's perspective, International Journal of Business and Management 6, 105–113.

Kemmoe, S., Lacomme, P. Tchernev, N. and Quilliot, A. (2011a). Mathematical formulation of the Supply Chain with cash flow per production unit modelled as job-shop. *IESM 2011*, May 25-27, Metz, France, 93-102, ISBN. 978-2-29600532-3-4.

Kemmoe, S., Lacomme, P. Tchernev, N. and Quilliot, A. (2011b). A GRASP for supply chain optimization with financial constraints per production unit", *MIC 2011*, 25th - 28th July, Udine, Italy.

Kemmoe, S., Lacomme, P. and Tchernev, N. (2012). Application of job-shop model for supply chain optimization considering payment delay between members, *ILS 2012*, August 26-29, Quebec, Canada.

S. Kemmoe, P. Lacomme, N. Tchernev, A. Quilliot

Kemmoe, S., Lacomme, P. Tchernev, N. and Quilliot, A. (2013). A GRASP for Supply Chain Optimization with Financial Constraints per Production Unit, in book "*Advances in Metaheuristics*, Series in *Operations Research/Computer Science Interfaces*, Di Gaspero L., Schaerf A., Stützle T. (Eds.): Springer Berling Heidelberg, ISBN : 978-1-4614-6321-4, 53, 161-186.

Najafi A.A., Taghi S., and Niaki, A. (2006). A genetic algorithm for resource investment problem with dis-counted cash flow, Applied Mathematics and Computation 183,1057-1070.

Petersen, K.J., Handfield, R.B., Ragatz, G.L, (2005). Supplier integration into new product development: coordinating product, process and supply chain design, Journal of Operations Management, 23, 371–388.

Pinedo, M. (2012). *Scheduling: Theory, Algorithms and Systems*, 4th edition, 686 pages, Springer.

Roy, B., Sussmann, B. (1964). Les problèmes d'ordonnancement avec contraintes disjonctives, *Note DS no. 9 bis*, *SEMA*, Paris, 1964.

Russell, A.H., (1970). Cash Flows in networks, Management Science 16, 357-373.

Russel A.R., (1986). A comparison of heuristics for scheduling projects with cash flows and resource restriction, Management Science, 32/10, 1291-1300.

Stadtler H. (2005). Supply chain management and advanced planning—basics, overview and challenges, European Journal of Operational Research 163/3, 575-588.

Tsai, C.-Y., (2008). On supply chain cash flow risks, Decision Support Systems 44, 1031–1042.

Tsai, C.-Y., (2011). On delineating supply chain cash flow under collection risk, International Journal of Production Economics 129, 186–194.

Ulusoy G. and Cebelli, S. (2000). An equitable approach to the payment scheduling problem in project management, European Journal of Operational Research 127,262-278.

Vickery, S.K., Jayaram, J., Droge, C., Calantone, R., (2003). The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships, Journal of Operations Management, 21, 523–540.

Vijayasarathy, L.R., (2010), Supply integration: an investigation of its multi-dimensionality and relation-al antecedents, International Journal of Production Economics, 124, 489–505.

Zhengwen H. and Xu, Y. (2008). Multi-mode project payment scheduling problems with bonus-penalty structure, *European Journal of Operational Research* 189/3, 1191-1207.

Innovative Product-Services for Robust Global Supply Chains – a Viewpoint

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Abstract
Global supply chains are subject to many disruptions of different kinds. In order to transform the existing rigid supply chains into shock-robust networks two dimensions have to be regarded: the supply chain dimension and the manufacturing dimension. On the supply chain dimension new product-service models are regarded which allow for a much higher service level and thus for a better resilience of the whole network. The manufacturing dimension enables these innovative product-service models by addressing the production processes of the individual player. Therefore an EU project has just started to conduct research on innovative decision-making methods which integrate production planning at single players into the management of the whole global network. Advanced tools will be implemented in a management cockpit at each player. CPS-data feed the cockpits and will give a clear view of the actual statues of the whole supply chain which drastically reduces complexity.

Keywords: Robustness, Supply-Chain, Product-Services

1. Introduction

The economies around the world are dominated to a large extend by complexity and dynamics [Lanza & Peters, 2012]. The current ambivalent situation within the automotive industry with OEM in serious crisis such as Opel in Germany, Fiat in Italy, PSA in France and others like VW or BMW in Germany with track records shows that a sustainable globalization strategy adaptable to changes in markets and legislation is of crucial importance for the future. Figure 1 shows the high volatility in the German automotive market with spreads up to 50% in both directions.

But the natural and nuclear disaster in Japan in 2011 or the impacts of economic uncertainty in some regions in the south of Europe show in very dramatic ways how fragile global supply chain networks can be. The increase of disruptions to industry is illustrated by Figure 2. Sustainable moves in economic crisis and fast reactions to disruptions and changed conditions (e.g. legal policies) become of crucial importance for all companies as they all are part of a global network. Moreover, customers all over the world expect a high degree of individuality and short delivery times. Variants are increasing and product life cycles become shorter.

Consequently, the ability of the production system and the supply network to evolve in synergy with the evolution of the product via reconfigurability, flexibility, transformability and agility becomes a key enabler of success [Wiendahl et al., 2007; Tolio et al., 2010].

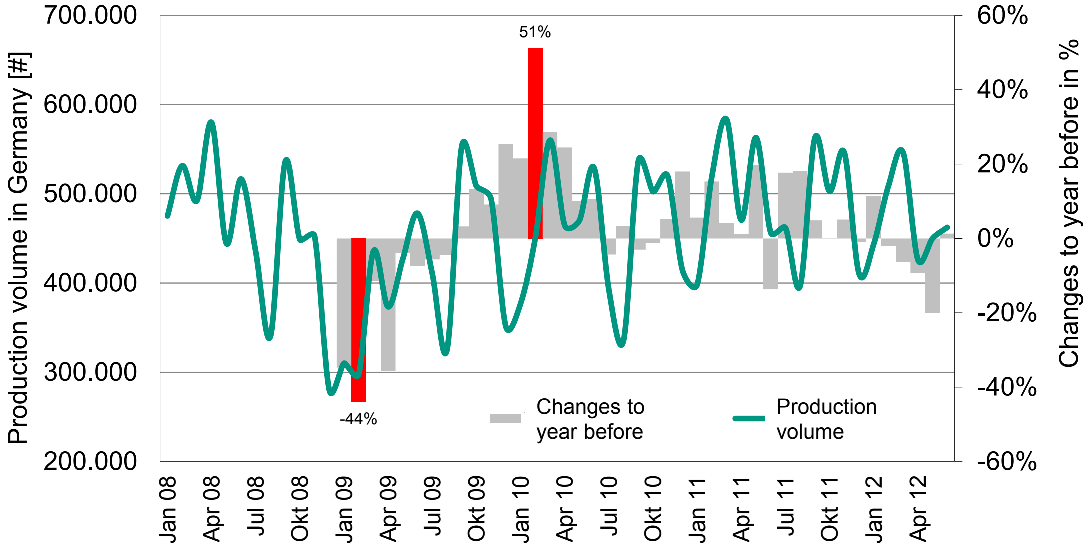


Figure 1: German automotive market development [Lanza et al., 2012]

2. Idea of shock-robustness

Manufacturing is radically challenged worldwide by complex economic, socio-political and technological dynamics that have a tremendous impact on enterprise behavior in the market. Many external drivers are modifying the way products are designed and exploited. For example, the introduction of new materials, technologies, services and communications, the pressure on costs and the attention paid to sustainability specifications. Furthermore, the need to increase company competitiveness is leading to solutions such as product-services. In this case, products are designed as more complex entities, with the physical product enriched by service and communication activities. Thus, external changes ("shocks") create a multitude of possible scenarios that companies must face in order to stay competitive. The outcome is often unpredictable and this represents a major cause of complexity when operating in dynamic manufacturing environments together with a lack of unified solution approaches.

Facing these challenges, a consortium of 4 universities and 7 industrial partners has been formed to deal with this disturbances and to work on concepts for shock-robust plants and networks. The major idea that leads this EU-project is the necessity to increase the shock-robustness of each player (plant level) within a supply chain or production network in order to increase the overall shock-resilience of the network (network level). In the following, existing approaches for increasing the robustness of manufacturing and networks are discussed.

2.1. Plant Robustness

The improvement of a factory's resilience to exogenous disturbances can be achieved in several ways. For example, high flexibility and reconfigurability of manufacturing provides the ability to react to short-term fluctuations in demand. Furthermore, modern sensors (e.g. condition monitoring systems) and methods of reliability engineering allow opportunistic maintenance strategies to prevent unplanned breakdowns and production stops. In addition, innovative business models for machine manufacturers and operators are the result of these developments. In the following, these measures for increased plant robustness are presented in more detail.

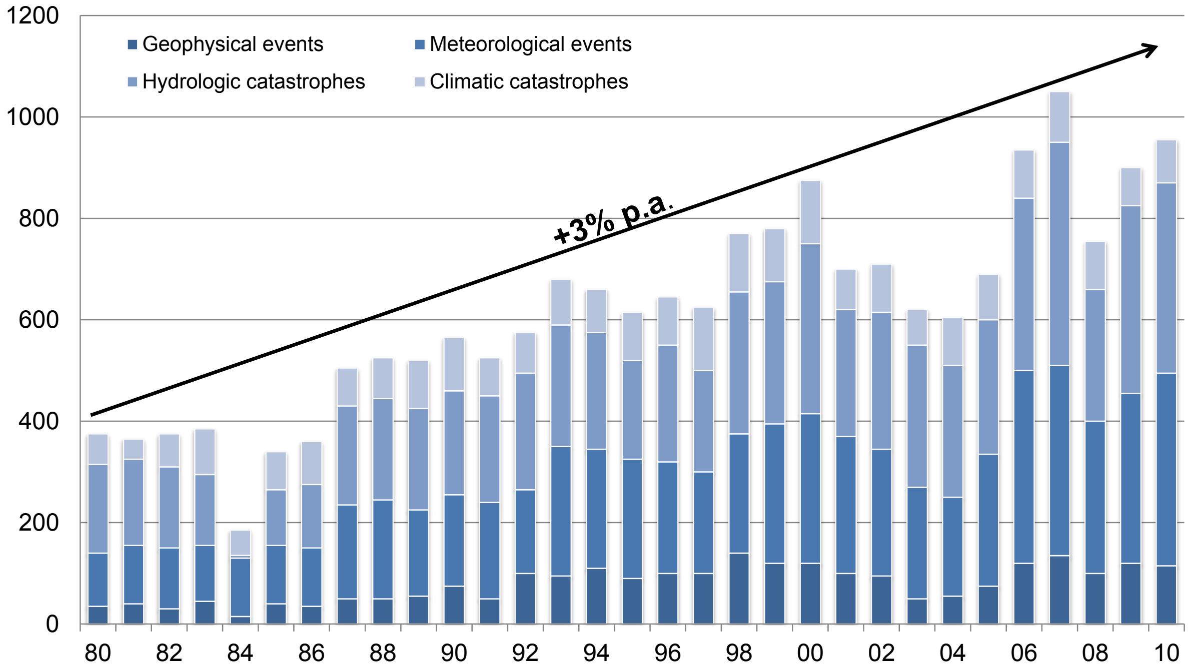


Figure 2: Number of disruptive events [McKinsey, 2012]

Reconfigurability / Flexibility

The challenge to increase the plant robustness can be addressed on multiple levels specific to the industry and markets (e.g. flexibility, reconfigurability, modularity, technology migration). Relevant approaches of flexibility or reconfigurability (compare [Wiendahl et al., 2007] for definition) can be divided into two major fields (compare [Lanza & Peters, 2012]): on the one hand, detailed models for analytical and simulative evaluation and optimization of manufacturing systems at one existing plant. They can be applied, for example, for capacity or material flow planning [Tempelmeier, 2003] or scheduling [Váncza et al., 2004]. On the other hand, there are approaches, dealing with supply chain or value adding networks [Weiler et al., 2011; Stephan et al., 2010; Leung et al., 2007], which often operate on a high and strategic level of abstraction. Moreover, optimization is often performed with respect to single time points or different scenarios and stochastic effects are not considered. One major disadvantage of reconfigurability / flexibility on plant level is the fact that companies optimize their own business without explicitly considering the effects of supply chain (e.g. late sharing of information).

Maintenance

In the past, maintenance was regarded as repair work and was fulfilled after a machine breakdown. Under today's production conditions, unplanned downtimes have to be minimized due to cost-intensive production lines and large spare parts buffers are not affordable due to cost reduction programs. Therefore, industry is demanding solutions for improved maintenance operations. Although preventive maintenance operations are scheduled, requests for equipment maintenance and component substitutions are often not permitted by production when production is fully operated for meeting short-term demand. This leads to delayed service operations and thereby to reduced service levels. To avoid these situations, industry is requesting solutions for opportunistic maintenance, enabling to delay maintenance operations to situations when the demand is lower and the inventory is higher, in order to partially hide the downtime. For an optimized scheduling of maintenance operations under the mentioned circumstances, an extensive knowledge of the failure behavior of machines and their components is required. With concepts of reliability engineering, multivariable relationships between external variables (e.g. process forces) and stochastic failure behavior is modeled and the reliability or rather the expected machine lifetime is computed [ReliaSoft Corporation; Cox & Oakes, 1984]. This makes the planning of opportunistic strategies possible and enables innovative business approaches such as optimized spare part provision [Niggeschmidt, 2010] or optimal service personnel planning [Lanza et al., 2010]. To take full advantage of these possibilities, it is sometimes necessary to involve the equipment spare parts producer in the maintenance process and to implement improved multi-sensor networks for continuously detecting degraded states of the resources, for a better maintenance planning. Moreover, predictive maintenance solutions are not ideal in very turbulent demand scenarios. They are based on the monitoring of single resource conditions and they do not consider the overall process chain needs and current demands. Also, no systematic cost-benefit transparency is given before service provision.

Recently, the integration between maintenance, production planning and quality control has been suggested [Colledani & Tolio, 2012]. Indeed, there is industrial evidence that production and quality control, equipment degradation and maintenance are strongly inter-related. For example, producing at higher utilization and speed increases the equipment degradation, thus leading to increased spare part requirements. Moreover, spare parts shortages can affect the continuation of production and will have to be available in stocks or made readily available through a responsive service from the equipment supplier. However, formal methods and tools to support the implementation of these promising approaches at shop floor level are still undeveloped.

Innovative business models

Business model innovation is an innovative concept in the European manufacturing industry. Traditionally, innovation was primarily based on technology innovation. Equipment suppliers were eager to offer new and innovative equipment, with a limited number of additional product-related services. The relationship with customers was mainly restricted to the selling transaction. The internal capabilities of equipment producers were mainly focused on technical issues. In recent years, the European industry competitiveness has been stained by the increasing turbulence of the market, determined by the presence of competitors from emerging countries. To face this situation, companies try to innovate their business models towards the establishment of long-term relationships with their customers and the provision of value-added services beyond the technical ones [Wiendahl et al., 2004]. Even if this trend is already recognized and accepted by equipment producers, it is still far from being implemented and achieved [Lay, 2007]. The main reasons have been identified in the lack of specific managerial culture and of operating tools supporting this deep change, which requires market, technical, financial organizational and supply chain knowledge and innovation.

In [Seliger et al., 2004] the idea of delivering services for the system adaptation and enable module re-use for different customers was proposed. More recently a strategic view for developing such services has been suggested [Scholz-Reiter et al., 2007]. Finally, the research stream Industrial Product Service Systems (IPS2) has been launched, with the objective of investigating benefits and operating modes for implementing the product-service idea in B2B relations. A first attempt towards the implementation of such concepts has been done recently in the European funded projects “Mantys” and “NEXT” in EU framework program FP6 (cp. Fig. 3).

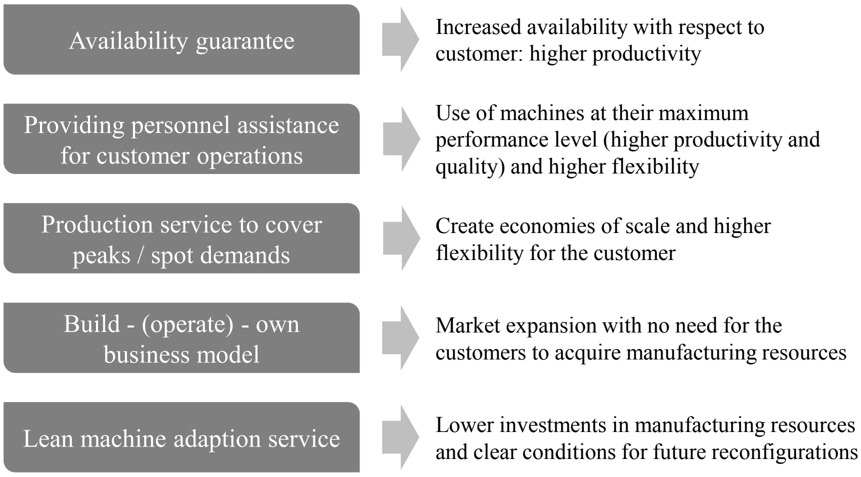


Figure 3 New business models investigated in the FP6 EU project NEXT

Even if the interest in this area is, without any doubt, rapidly increasing, the research results currently available to companies are mainly at strategic and conceptual level, featuring the following limitations:

- The link between strategy and concrete operations is still missing and this partly explains the slow adoption rate of New Business Models by European manufacturing companies.
- The impact of dynamic networking in the supply chain structure and collaborative design approaches on the implementation of the product-service idea has not been stressed and companies do not manage effective methods to implement the new business models at operational level.
- Software solutions to enable collaborative implementation of the services and field data collection are poorly developed.
- Available business models related research has been traditionally addressed from the point of view of the equipment producer, very rarely having the user (OEM or customer) as target stakeholder. This ended up in solutions difficult to value and implement at industrial level.

Often the implementation of innovative business models fails due to technological barriers and limitations. The EU- project aims at providing a set of new technological and methodological solutions to profitably manage the implementation of new business models at operational level.

Risk Management in Manufacturing Systems

Currently, delivered B2B service models do not effectively address risk-sharing and the supply chain stakeholders are still reluctant in sharing internal information. For example, some machine tool builders provide remote monitoring services (e.g. Mori Seiki, TRUMPF). However, machine tool users are reluctant to accept such services with the idea to protect themselves from possible penalties in the contract warranties due to suboptimal use of the resources. In this way, there are huge potential benefit losses related to services that prove to be more efficient if a long term cooperation and trust relation is established between the equipment supplier and the user.

For instance the automotive industry is under continuous pressure to reduce costs arising from both increasing competition and complexity of operations [Ellis et al., 2010; Wagner & Silveira-Camargos, 2012]. To deal with this challenge is to outsource value creation to the supply network. The tight buyer-supplier relationships operate with short reaction times and are characterized by high time dependency and minimal buffers. It increases the risk exposure of buyers to disturbances. The risk thematic is not new in automotive, but a growing subject in supply chain management.

Supply chain risk has multiple sources including process, control, demand, supply and environment and requires more specific and adequate responses like more exact techniques which incorporates economics [Hoffmann, 2011]. Risk analysis could provide more accurate assessments of risk if there were better integration of economics into risk assessment itself [Lavastre et al., 2012]. To explore the relations between representations of supply disruption risk like, magnitude of supply disruption, probability of supply disruption and overall supply disruption risk economics can be useful. Supply chain configurations can be generated with a computational synthesis tool [Schotborgh et al., 2008]. It generates solutions based on knowledge rules and design requirements, presenting an overview of the solution space. The supply chain design problem is a complex process where a number of decisions have to be made, which influence the outcome.

2.2. Supply Chain Robustness

Production based on value added networks is playing an ever more important role against the backdrop of increasingly globalised sales and procurement markets [Dunning, 1992]. The increasing dynamics of the economic environment and changing competitive conditions turn the global coordination of corporate value added activities into a key factor for success [Schmenner, 1982; Khurana & Talbot, 1998]. The organization of production networks involves the selection of suppliers, the assignment of products to suppliers, the location of production nodes as well as the design of the distribution system. All these decisions determine the flow of materials, information and financial assets within the network. Hence, it is a fundamental scientific and engineering attitude to improve these structures and flows, as far as possible.

Production network planning and optimization

Production networks are rarely constructed from scratch but rather develop over time [Grunow et al., 2007]. Hence, the actual structure of a network constrains its future shape. A number of aspects may influence the restructuring efforts, like the maturity of the products, number of products to be potentially relocated, adequate resource capabilities for test runs, as well as ramp-up efforts. Naturally, issues which influence the complexity and the vulnerability of the network also have to be considered, such as the variety of products produced at a location, the assignment of products to various production facilities, responsiveness to unexpected changes in the environment, exchange rates volatilities, etc. Nevertheless, current supply chain coordination methods are not able to cope with very dynamic environments and lack effectiveness under fluctuating production requirements. For example, the Just in Sequence (JIS) planning method is widely implemented for customized, large-variety productions. However, its rigidity and need for standardization mines the robustness of the entire supply chain. It is not uncommon that very unpredictable, even minor events, such as accidents during the components delivery, directly cause delayed final product deliveries to the customer. Alternatively, expensive buffers (e.g. in logistics centers) are used for decoupling, today.

Though, in lack of any central agency (or a powerful dominating partner) the organization of a network in order to reach a global optimum is problematic. Considering open network structures and a multiplex role of partners in several production networks the idea of holistic optimization is doubtful [Bretzke, 2009]. The usual optimization criteria are cost, service and inventory levels, and recently, flexibility and changeability [Wiendahl et al., 2007]. Besides checklist procedures and scenario-based economic feasibility analyses, model-based simulation and optimization approaches are proposed in literature to tackle the planning and coordination of supply chains and production networks [Jacob, 2006]. Model-based simulation approaches use a model to assess performance with regards to specific target parameters. Distinctions can be made between static and dynamic approaches and deterministic and stochastic inputs [Persson & Olhager, 2002; Kleijnen, 2005; Longo & Mirabelli, 2008]. The model-based optimisation approach adds an optimisation algorithm to the simulation which either maximises or minimises a target value by modifying the parameters of the model in different degrees of freedom. This approach allows for the same distinctions between dynamics and uncertainty of input data. [Melo et al., 2009; Meixell & Gargeya, 2005; Peidro et al., 2009] give a broad overview over optimisation approaches in the field of production network planning or supply network planning taking uncertainties into consideration. [Maropoulos et al., 2006] introduced a framework for collaborative design and production network development. The core idea was the parallel and synchronous design and evaluation of the product, the production process and the production network by the synthesis and evolution of four methods: (1) resource aware planning, (2) Digital Enterprise Technology (DET), (3) non-linear control for logistics optimization, and (4) the concept of emergent synthesis.

There are a number of problems while managing supply chains in unforeseen, frequently changing, volatile environment. Often, the structure of the chain/network is relatively rigid. The partners make decisions based on asymmetric information, moreover uncertain information while the transparency in the overall chain is very limited.

Use of cyber-physical systems to increase network robustness

The so called "Fourth Revolution of Industry" addresses the change based on modern technologies of ICT in traditional industrial processes. Future industrial production is characterized by an increasing individualization of products, which are linked by integrated ICT functionality to each other and to the Internet.

Merging of the physical with the cyber world in so called cyber-physical systems (CPS) opens up new opportunities for production, for instance the realization of robust, networked production systems and instant re-scheduling. The centerpiece is a network of autonomous, self-configuring, knowledge-based and spatially distributed sensors in production systems and resourced itself (e.g. production machines, robots, transporters), including their planning and control systems. CPS will become part of all critical components in products and machinery in order to enable transparency for continuous improvement and allow partially automated control loops in plants and networks to increase efficiency and robustness. Information about states of a component, a machine or whole lines, plants and networks can be collected in almost real-time. Thereby human-machine interaction can be improved as machines and automation devices become more sensitive for their environment. “Europe – and Germany in particular – are global market leaders in major areas relating to CPS, such as embedded systems and mobile communication networks” [Acatech, 2011].

3. Approach

The mentioned aspects lead to the necessity of a transformation process from a hierarchical supply chain to networks based on partnership with a new understanding of business approaches and services along the partners. In order to gain such a network two levels have to be regarded as mentioned in chapter 2: Supply Chain Level and Plant Level. Given a robust plant the supply chain mechanisms, especially the product-services which are connecting the players along the supply chain can be focused. Therefore, research on innovative decision-making methods which integrate production planning at single plants into the management of the whole global network has to be conducted. Risk-sharing business models including information sharing and reliable technical sub-systems are key enablers. These approaches should be able to cope with upcoming uncertainty, quantify risk and reduce the complexity for the decision-makers to a minimum. This will lead to best possible conditions for networks in terms of flexibility and reliability. To cope with the challenges described above, a new understanding of customer-supplier-relations of the partners in the supply chain is required. This understanding will lead to innovative product-services which support the idea of a robust network on both, the supply chain and the plant level. On the supply-chain level different innovative product-services can be considered: component suppliers offer warranties according to quality of products, flexibility in quantities (for a previously defined price), delivery time, remanufacturing-contracts etc. Besides, there are product-services on the plant level, as for instance full-service warranties added to manufacturing equipment. So, within each plant along the supply chain it is not sufficient to restrict the object of interest to the player's own local production systems. In order to improve the robustness of a single player the cooperation with its equipment supplier needs to be regarded in order to achieve high availabilities of machines, etc. As already mentioned in chapter 2 different research areas arise: Reconfigurability, Maintenance, Innovative Business-Models and Risk Management. The approaches in these areas can be part of the plant level and /or the supply chain level as can be seen in Figure 3. All approaches belong to three different topics: Product-Services, Enabling Technologies or Analyzing Techniques.

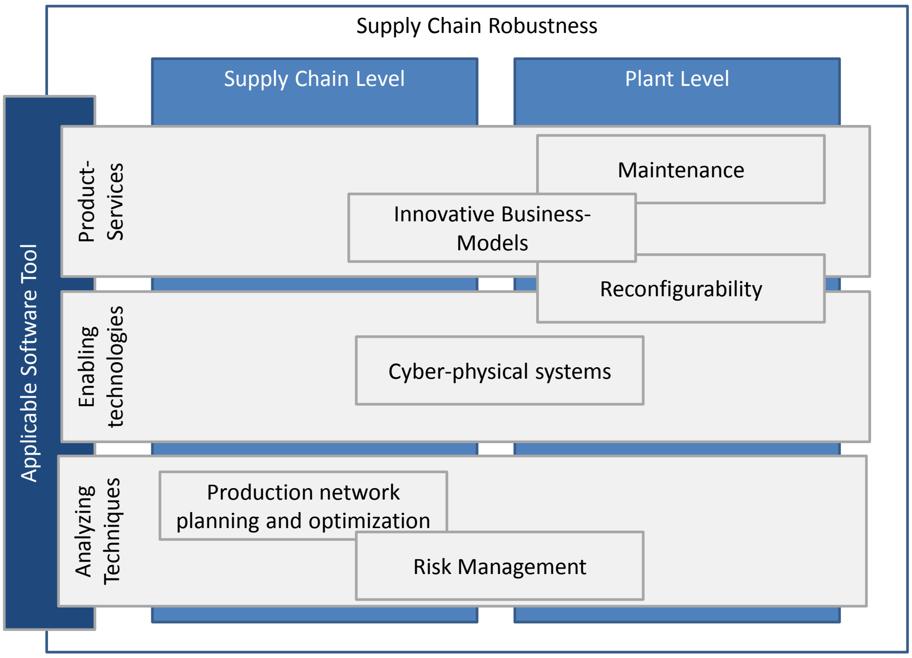


Figure 4: Research topics in the overall approach

The three mentioned topics will form an applicable software tool that is able to analyze current situations on the basis of almost real-time data form the cyber-physical systems. Given the analyses of the current situation this toll allows to choose or configure according product-services. These features shall not be restricted to local systems in the supply chain. All partners along the supply chain can use the same tool and partly the same databases in order to gain a situation which is preferable for the whole supply chain.

Reconfigurability

There is lack of reconfigurable production technologies and systems able to be quickly adapt themselves to given changes. In that sense reconfiguration is not only the physical change of a machine or a whole production system, but also change in production planning like rescheduling.

The approach will address both fields. The rescheduling of a production can be a plant-internal change which can be performed on plant level. However, changes also affect the supply chain, as different components may be needed or the products will be finished at different dates than expected. These effects will be regarded and rescheduling approaches will be developed. Reconfiguration of machines on the other hand is a service from the equipment supplier to the OEM and will be regarded and analyzed as such.

Maintenance

Moreover, predictive maintenance solutions are not ideal in very turbulent demand scenarios. Moreover, imprecise load information impedes the lifetime prognosis of critical components.
Preventive maintenance solutions are based on the monitoring of single resource conditions and they do not consider the overall process chain needs and current demands. Also, no systematic cost-benefit transparency is given before service provision. Therefore, maintenance activities should be linked with the overall system condition. Specifically, additional thresholds will be imposed to activate maintenance interventions only when there is enough security stock downstream in the process chain, in order to hide the maintenance time and reduce its impact on the service level. Therefore, real load data derived from advanced sensor technologies for data acquisition (e.g. condition monitoring and security stock level) are needed which can build the input of statistical reliability models. Based on the reliability analysis new opportunistic maintenance policies are developed. These policies only activating maintenance operations when the machine is in a serious degradation state and the safety inventory stocks are above certain predefined security thresholds. In order to be able to perform the maintenance activities according to the opportunistic maintenance policies innovative planning methods for spare part provision and service personnel planning are needed. Here conflicts can arise in the case of simultaneous maintenance requests. So, innovative tools for the effective priority management of repair personnel's interventions need to be developed, too.

Innovative Business-Models

As stated in chapter 2 the existing business models often focus on a strategic level. So, it can be difficult to implement them on an operational level. Besides, the current business models hardly take dynamic environments and changes into account. If the OEM faces changes in demand, these changes will also affect its suppliers. However, a changing quantity of delivered components may not be part of the existing contracts, so new negotiations are needed whenever changes are faced. Also, the available business models hardly address the point of view of the customer but are only developed with respect to the service provider's interests. For example, a TCO (Total Cost of Ownership) contract only stays valid, if the corresponding machine's task does not change during the warranty period. Thus the OEM is unable to produce different parts on the machine. The given weaknesses in existing business models will be addressed by the idea of continuous information sharing as the very basis for the development of new innovative business models. If changes occur, e. g. unexpected demands that cause a shift in the product mix to produce, the new situation will be analyzed, e. g. effects on the machines (changes on the resulting forces, etc.) and the results of the analysis will be given to the suppliers who in turn can dynamically adapt the contracts according to the varying circumstances within the given new flexible business model. In order to analyze the given information, new innovative analyzing techniques are needed. The inputs of these analyzing techniques are different data sets which need to be known. Therefore, enabling technologies in hardware (e.g. sensors) and software are developed and implemented. Different business models will be focused first:

- component supplier level: advanced mechanisms for flexible delivery warranties

- equipment supplier level: advanced equipment monitoring and predictive maintenance services as well as equipment reconfigurability services.

Risk Management

Currently, delivered B2B service models do not effectively address risk-sharing, especially when regarding the supply chain as a whole. By information sharing along the supply chain we attempt to gain advantage from an integrated view of the manufacturing system at shop floor level and the production network structure at global level. Effects of the market will be included in the stochastic, dynamic optimization to find optimal product-services for the given current situations. The main innovations herein are:

- All different levels are integrated in one method. So, risk analyses are enabled along the whole supply chain. Therefore, a supply-chain model needs to be developed which includes mechanisms for decision-making. Using this model knowledge of the supply chain effects deriving from individually optimized company decisions can be gained. This knowledge will be the starting point for the development of innovative business models.
- As the supply chain effects are known optimal product-services can be chosen according to the given dynamic environment. These product-services can be used on plant level or on supply chain level. For the optimal configuration of product-services on both levels technical and methodological solutions are developed.
- The optimal product-service configuration will be tested to their risk distribution among stakeholders and their effects on the robustness of the whole network.

Production network planning and optimization

Nevertheless, current supply chain coordination methods are not able to cope with very dynamic environments and lack effectiveness under fluctuating production requirements. In order to increase coordination methods different simulations and algorithms will be developed. The supply chain will be simulated in an agent-based framework. Each partner in the supply chain will be represented by a self-optimizing player. The framework will support the decisions in the supply chain and will allow simulating "what-if" tests. Given the framework special algorithms will be developed for risk-analysis of production networks and planning of flexible production networks. Besides changes and disturbances in dynamic production networks need to be detected as early as possible.

Use of cyber-physical systems to increase network robustness

In order to make use of the potentials given by cyber-physical systems (see chapter 2) it is necessary to develop CPS which can be used at shop floor level. Therefore a detailed specification of the given conditions at shop floor will be given. Not only technical requirements are of interest, but also the social aspects (e. g. experiences in handling sensors). Form a technical point of view the long distances between the sensors, the vibrations and dust will be main problems. Given this detailed specification prototypes of CPS will be developed and implemented. These prototypes shall be able to track real-time load profiles of machines to give the databases for improved condition statements and thus for reliable systems and intelligent fast rescheduling.

4. Conclusions

By the development and integration of one applicable software tool for all partners and by sharing relevant information with the partners in the supply chain, a preferable configuration of the supply chain as a whole can be gained. The dynamically changing databases and the ongoing analyses allows to adapt the supply chain to changes and thus to generate a robust supply chain. The named research areas either focus on the plant level robustness, or on the supply chain level. On both levels the described analyzing and planning tools rely on a good database along the supply chain. So, enabling technologies are important. Given the CPS, sources for new innovative analyzing techniques are given. These techniques in turn allow for risk sharing models which lead to new innovative business models. These models will be able to sustain in dynamic environments and will lead to a robust collaboration along the supply chain.

5. Summary

Today's manufacturing supply chains face a highly volatile environment. Examples for dynamically changing factors are various (economic factors as demand fluctuation, labor costs, exchange rates as well as climate shocks, etc.). Given this unstable environment and additional internal disruptions like machine breakdowns it becomes obvious that robustness is of crucial importance for manufacturing supply chains. In order to face all these challenges an approach is made which focuses on different topics on plant and on supply chain level. The leading idea is that robust plants and robust interaction mechanisms between the plants (product-services) lead to a robust supply chain. The basis for both, the robust plants and the robust interactions is a commonly used database for innovative planning and analyzing tools as well as enabling technologies like cyber-physical systems which are able to provide crucial data. Given that basis the topics of Reconfigurability, Maintenance, Innovative Business-Models, Risk Management and Production network planning and optimization are regarded in an integrated research approach and will enable the development of advanced analyzing and planning tools. These will lead to robust plants and robust interactions and optimized information sharing on the basis of product-services in order to increase the supply chain robustness.

6. References

Acatech: Cyber-Physical Systems Innovationsmotor für Mobilität, Gesundheit, Energie und Produktion 2011

Bretzke, W.-R., 2009, Supply Chain Management: Notes on the Capability and the Limitations of a Modern Logistic Paradigm, *Logistics Research*, 1/2:71–82.

Colledani M., Tolio T., "Integrated Quality, Production Logistics and Maintenance Analysis of Multi-Stage Asynchronous Manufacturing Systems with Degrading Machines" CIRP Annals – Manufacturing Technology 61 (2012), 455-458.

Cox, D. R., and Oakes, D., 1984: Analysis of Survival Data, Chapman and Hall, London, New York.

Dunning, J. H. (1992). The global economy, domestic governance, strategies and transnational corporations: interactions and policy implications. Transnational Corporations, 1(3), 7-45.

Ellis S.C., Henry R.M., Shockley J., 2010: Buyer perceptions of supply disruption risk: A behavioral view and empirical Assessment, Journal of Operations Management, 28, p.34–46 .

Grunow, M., Günther, H.O., Burdenik, H., Alting, L., 2007, Evolving Production Network Structures, *CIRP Annals - Manuf. Tech.*, 56/1:427–430.

Hoffmann S., 2011: Overcoming Barriers to Integrating Economic Analysis into Risk Assessment, Risk Analysis, Vol. 31, no. 9,p.1345-1355 .

Jacob, F., (2006), Quantitative Optimierung dynamischer Produktionsnetzwerke, Shaker Verlag, Aachen.

Khurana, A., & Talbot, B. (1998). The internationalization process model through the lens of the global color picture tube industry. Journal of Operations Management, 16(2), 215-239.

Kleijnen, J. P. (2005). Supply chain simulation tools and techniques: a survey. International Journal of Simulation and Process Modelling, 1(1), 82-89.

Lay G., 2007, Betreibermodelle fur Investitionsguter – Verbreitung, Chancen und Risiken, Erfolgsfaktoren, Fraunhofer ISI, Karlsruhe.

Lanza, G.; Behmann, B.; Werner, P., 2010: Enhancement of the serviceability in the machine and plant industry. Proceedings of APMS (International Conference on Advances in Production Management Systems) ISO TC 213 Dimensional and geometrical product specifications and verification.

Lanza, G.; Peters, S., 2012: Integrated capacity planning over highly volatile horizons; in: CIRP Annals – Manufacturing Technology, Vol. 61, S. 395-398..

Lanza, G., Peters, S., Herrmann, H. G. (2012). Dynamic optimization of manufacturing systems in automotive industries. CIRP Journal of Manufacturing Science and Technology.

Lavastre O., Gunasekaran A., Spalanzani A., 2012: Supply chain risk management in French companies, Decision Support Systems, 52, p. 828-838.

Leung, S.; Tsang, S.; Ng, W.; Wu, Y., 2007: A robust optimization model for multi-site production planning in an uncertain environment; in: European Journal of Operational Research, 181, S. 224-238.

Longo, F., & Mirabelli, G. (2008). An advanced supply chain management tool based on modeling and simulation. Computers & Industrial Engineering, 54(3), 570-588.

Maropoulos, P.G., Kotsialos, A., Bramall, D.G., 2006, A Theoretical Framework for the Integration of Resource Aware Planning with Logistics for the Dynamic Validation of Aggregate Plans within a Production Network, *CIRP Annals - Manuf. Tech.*, 55/1:483–486.

McKinsey, 2012: The Future of Manufacturing, World Manufacturing Forum, Stuttgart, 16.10.2012.

Meixell, M. J., & Gargeya, V. B. (2005). Global supply chain design: A literature review and critique. Transportation Research Part E: Logistics and Transportation Review, 41(6), 531-550.

Melo, M. T., Nickel, S., & Saldanha-Da-Gama, F. (2009). Facility location and supply chain management–A review. European Journal of Operational Research, 196(2), 401-412.

Niggeschmidt, S., 2010: Ausfallgerechte Ersatzteilbereitstellung im Maschinen- und Anlagenbau mittels lastabhängiger Lebensdauerprognose. Karlsruher Institut für Technologie (KIT), Dissertation.

Peidro, D., Mula, J., Poler, R. & Lario, F.C., (2009). Quantitative models for supply chain planning under uncertainty: a review, International Journal of Advanced Manufacturing Technology, 43(3-4), 400–420.

Persson, F., & Olhager, J. (2002). Performance simulation of supply chain designs. International Journal of Production Economics, 77(3), 231-245.

ReliaSoft Corporation: Reliability Engineering. Source: http://weibull.com/. Tucson (Arizona, USA), 2008.

Scholz-Reiter B., Krohne F., Severengiz S., Adaptation Service Manager for Manufacturing Equipment, Proceedings of the 40th CIRP Manufacturing System International Conference, 2007.

Schotborgh W.O., Kokkeler F.G.M., Tragter H., Bomhoff M.J., van Houten F.J.A.M., 2008: A Generic Synthesis Algorithm for Well-Defined Parametric Design, CIRP Design Conference.

Schmenner, R.W. (1982), Making business location decision. Education, Englewood Cliffs.

Seliger G., Consilgio S., Zettl M., Selling use instead of Selling Products – Technological and Educational Enablers for Business in Ecological Product Life Cycle, In Product Life-Cycle Quality Management Issues, 2004.

Stephan, H.A., Gschwind, T., Minner, S., 2010: Manufacturing capacity planning and the value of multi-stage stochastic programming under Markovian demand; Flexible Services and Manufacturing Journal, Volume 22, Numbers 3-4, Springer, p.143-162.

Tempelmeier, H., 2003: Practical considerations in the optimization of flow production systems, International Journal of Production Research, 41, No. 1, p.149-170.

Tolio, T., Ceglarek, D., Elmaraghy, H. A., Fischer, A., Hu, S. J., Laperriere, L., Newman, S. T. and Vancza, J., 2010. SPECIES-Co-evolution of products, processes and production systems. CIRP Annals - Manufacturing Technology, 59 (2), pp. 672-693.

Váncza, J., Kis, T., Kovács, A., 2004: Aggregation - the key to integrating production planning and scheduling, CIRP Annals - Manufacturing Technology, Volume 53, p.377-380.

Wagner S.M., Silveira-Camargos V., 2012: Managing Risks in Just-In-Sequence Supply Networks: Exploratory Evidence From Automakers, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, vol. 59, no. 1, p. 52-64.

Weiler, S., Páez, D., Chun, J.-H., Graves, S., Lanza, G., 2011: Supply chain design for the global expansion of manufacturing capacity in emerging markets; in: CIRP Journal of Manufacturing Science and Technology, Volume 4, p.265-280.

Wiendahl H.-P Andersson P., Berggre C., Nehler C., 2004, Manufacturing Firms and Integrated Solutions: Characteristics and Implications, European Journal of Innovation Management, Vol 7, n°1, pp. 218-228.

Wiendahl, H.-P. ElMaraghy, H.A. Nyhuis, P. Zäh, M.F. Wiendahl, H.-H.; Duffie, N.; Brieke, M., 2007: Changeable Manufacturing - Classification, Design and Operation; in: CIRP Annals – Manufacturing Technology, Vol. 56/2, S. 783-809.

insurances to transfer the risks (Jüttner, 2005; Khan and Burnes, 2007; Norrman and Jansson, 2004; Siebrandt, 2010).

4 SCRM at outsourced logistics

4.1 Importance of LSPs in SCRM

As stated by Sodhi and C.S. Tang (2012) transportation can be the Achilles' heel in SCM. Unfortunately, SCM and SCRM often overlook or neglect the important aspect of physical distribution and transportation, despite the fact that these activities form the backbone of SCM (Peck, 2006; Siebrandt, 2010). The stable and reliable flow of inbound products and services is one of the most critical activities in SCRM (Burt et al., 2003) and especially the increasing complexity in national and international transport systems makes it an important considerations for all companies (Fawcett et al., 1993; Peck, 2006). Therefore, the supply chain strategy should not target only at lowest costs, but also to reduce the impact of disruptions (Christopher and Peck, 2004).

Advanced topics for risk management research in the area of logistics are network disruption analysis, freight transportation system resilience and delivery time reliability (Husdal, 2009; Spekman and Davis, 2004; Sullivan et al., 2009; Ta et al., 2009), i.e. focusing on specific problems from a system or stakeholder perspective. These topics are helpful for the aforementioned areas, but do not replace a holistic SCRM approach, especially as (road) transport is of course a key activity for LSPs, but the range of services is much broader.

Each company is a citizen of its supply chain and depends also on LSPs (Sheffi and Rice, 2005), either directly or indirectly. SCRM may not be as important in an arm's length relationship, as in a strategic alliance where sharing of information as well as risks and rewards of the relationship are common (Gentry, 1993). Nevertheless, risks have to be handled both before the outsourcing decision is made (e.g., in the tendering and contracting phases) and after the outsourcing decision when the LSP takes over his responsibilities (Andersson and Norrman, 2003).

In a recent survey, the increasing usage of LSPs by organizations to reduce their risks is shown (Langley and Capgemini, 2012b), but the role of a LSP is seen from two contrasting viewpoints in the literature:

- Risks are minimized for the shipper (Crone, 2006; Fawcett et al., 1993; Gentry, 1993), as shown by the benefits in Table 2. This is line with the corporate risk management perspective, where outsourcing is recognized as risk avoidance, risk transfer or risk reduction measure (Andersson and Norrman, 2004) and following the resource-based and network theories (Zacharia et al., 2011);
- Risks are increased for the shipper, driven by the risks presented in Table 2, which is also expressed in certain SCM literature (Peck, 2006; Zsidisin, Melnyk, et al., 2005).

4.2 SCRM of LSPs

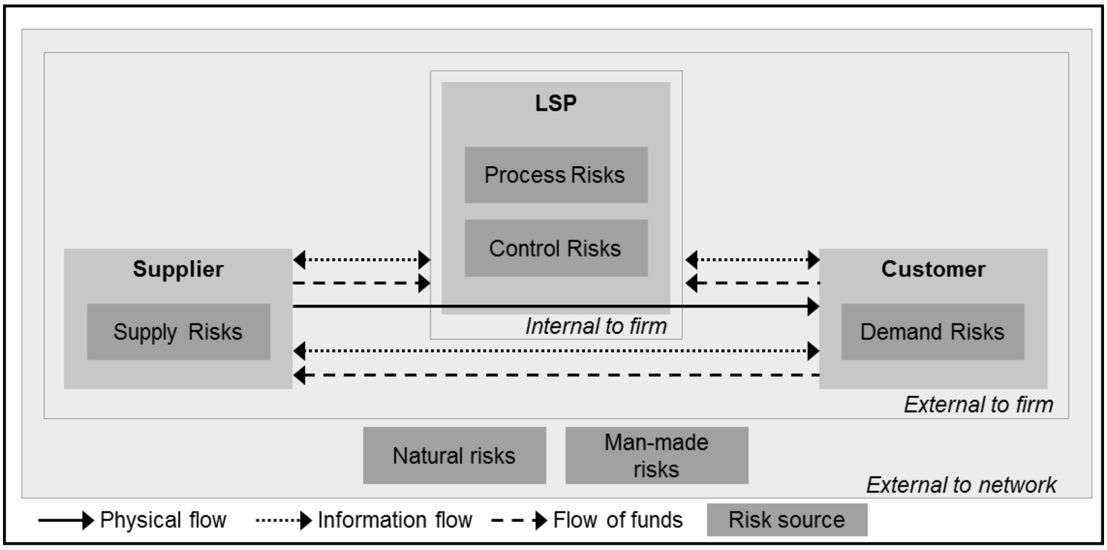
A holistic SCRM approach and implementation especially from the viewpoint of LSPs, is discussed only by few authors, which are summarized in Table 3. Other authors (e.g. Sanchez-Rodrigues et al., 2008, 2010; Wagner and Bode, 2009) include LSPs in their research or individual aspects of logistics or transport risks, but not as comprehensively as the listed authors, which have a main stake in this chapter. As stated by Wagner and Bode (2008), due to the numerous forms of services provided by LSPs as well as different business models of LSPs, a broad perspective of SCRM needs to be taken.

Table 3: Authors addressing holistic SCRM of and with LSPs

Source	Overall topic	Methodology	SCRM of LSP content
Andersson and Norrmann (2003, 2004)	Risk of shipper and LSP in outsourcing of advanced logistics services	Case Study (paired view of 1 Shipper and 1 LSP)	Specific risks shown, Risk management and contingency plans described, contract as key aspect for SCRM as preventive tool
Pfohl et al. (2008a)	SCRM of LSPs and industry and trading firms	Survey of 37 LSPs and 28 industry and trading firms	Current risk situation of LSPs (risk matrix), future risk development, importance and degree of implementation of risk management process, motivation for implementation, methods and KPIs applied, position in organization and responsibility, degree of collaboration along the supply chain
Iakovou et al. (2009)	Risk and security from LSP perspective	Literature review	Categorization of risk and security issues, methodological framework for mitigating logistics risks, overview of security regulations, certifications, IT systems and initiatives, measures to improve resilience and risk management process
Ojha and Gokhale (2009)	Scale development and validation of logistical business continuity management	Survey of 106 US LSPs	Multidimensional second-order factor model with key psychometric properties of SCRM with a focus on logistics.
Siebrandt (2010)	Risk management of LSPs	Research	Risk management process, legal requirements in Germany, detailed explanation of potential risk scenarios for LSPs, Organizational aspects

Based on Pfohl et al. (2008) and Sanchez-Rodrigues et al. (2008), we developed a comprehensive triadic risk view of the LSP (refer to Figure 4), including the risk sources defined in Figure 3. The flows can be disrupted from the risk sources that are either internal or external to the firm, or external to the network. Depending on whether the supplier or customer is the shipper for the LSP, not all information and fund flows may exist. This framework is important for suppliers as well as for customers, as they have to be aware of the potential risks for their logistics link in the supply chain.

Figure 4: Triadic risk view of LSP



Source: Adapted from Pfohl et al., 2008 and Sanchez-Rodrigues et al., 2008

Pfohl et al. (2008) list mainly operational risks (e.g., bad quality of client data or payment behavior of clients) as major risk sources, whereas Langley and Capgemini (2012b) name disruptive risks as the main threat. In the outsourcing relationship with the shipper, LSPs bear specific risks such as the investments required, the willingness of the shipper to share risks and potential opportunistic behavior of the shipper regarding business volume and scope

(Andersson and Norrman, 2003), but otherwise nearly the same risk categories as shown in Table 2 apply to the LSP.

In the literature, only one risk management process specific to LSPs was found (Iakovou et al., 2009) which is however very similar to the general risk management process as already described in Chapter 3.3. Ojha and Gokhale (2009) developed a psychometrically validated logistical business continuity planning scale with the following relevant elements:

- awareness of contact points, roles and responsibilities, continuity and recovery service levels,
- institution of business continuity reviews,
- development of business continuity processes,
- effective failure reporting and documentation,
- testing of continuity plans and training of employees.

According to Pfohl et al. (2008), a risk management process is only implemented at 51% of LSPs and out of these only 47% describe it as a well-structured approach. Siebrandt (2010) gives a very detailed description of each disruption risk and further practical information (e.g. estimation of occurrence probability in Germany, possible damages, and insurance possibilities) on each step of the risk management processes. For supply chain complexity and risks, 42% of the LSPs feel confident that they can reduce them, however only 22% of the shippers agree to this. Even worse, for supply chain disruptions only 27% of LSPs state they can help and only 17% of shipper feel confident (Langley and Capgemini, 2012a).

Tools to identify, assess and prioritize the risks which are logistic-specific comprise supply chain risk mapping, supplier audits, flow diagrams and critical path analysis (Pfohl et al., 2008). LSPs must not only identify the direct risks, but also the potential indirect risks at every significant and critical link along the supply chain as they can have a significant impact on the LSP as well, due to the high integration of supply chains (Iakovou et al., 2009).

The tools and strategies for LSPs to reduce risks by increasing the robustness or resilience of supply chains are extensive and include also strategies to improve the flexibility as explained in detail by Naim et al. (2010). We divided the overview from multiple sources in Table 4 between strategic and operational approaches.

Table 4: Strategies and measures to improve resilience or robustness

Strategic	Operational
▪ Closer partnerships ▪ Higher transparency in the supply chain ▪ Better talent management ▪ Improved continuity management ▪ Advanced risk management organization ▪ Reduced complexity	▪ Financial reserves (internal or by insurance companies) ▪ Better training of employees ▪ Back-ups of information systems and processes ▪ Multimodal transportation ▪ Multiple routes ▪ Increased temporal transportation flexibility

Source: Iakovou et al., 2009; Langley and Capgemini, 2012b; Naim et al., 2010; Sodhi and C.S. Tang, 2012; Wagner and Bode, 2009

4.3 SCRM of shippers with LSPs

The implementation of supply chain-wide risk management is a complex, but necessary task (Pfohl et al., 2010). The interplay of LSPs with shippers in SCRM is only discussed by Andersson and Norrman (2003, 2004), stating that contracts play an important role in SCRM, but shippers still have to bear most of the liabilities although not being responsible for the risk sources. According to Pfohl et al. (2008), 47% of shippers include the supplying LSP and 61% the delivering LSP in their risk management. When creating a resilient supply chain certain trade-offs have to be considered by shippers (Sheffi et al., 2003):

- Known supplier vs. lowest bidder: Known LSP can provide higher level of security, but also at higher costs than the arm's length relationship.
- Managing risks vs. delivering value: Additional costs for LSP and shipper on a daily basis to mitigate risks.
- Collaboration vs. secrecy: Collaboration with LSP improves the resilience, but increases also the risks of lost information.
- Redundancy vs. efficiency: Redundancy (e.g. stock buffers or multi-carrier approach) increases the resilience, but at higher costs.

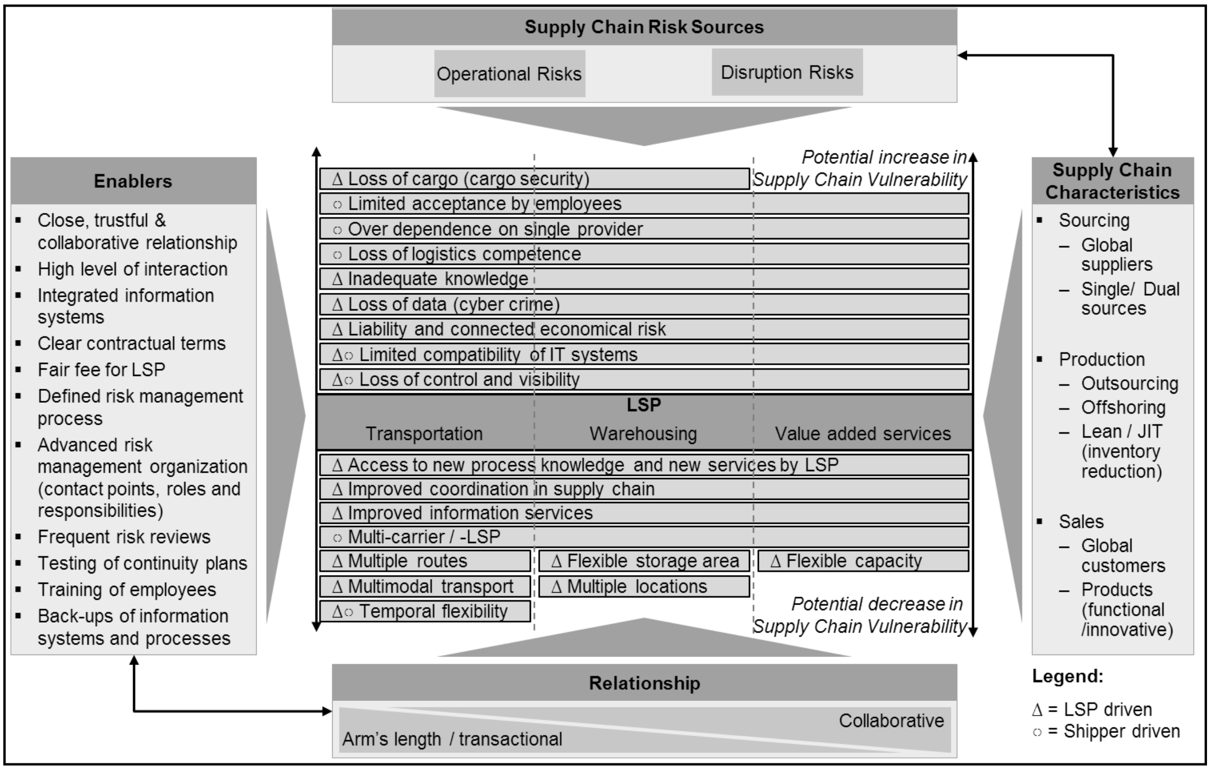
The willingness to have a close and collaborative relationship, clear contractual terms, a fair fee for LSPs, and the use of integration-enabling technology by LSPs and their clients is a prerequisite for a successful partnership (Crone, 2006; Iakovou et al., 2009; Siebrandt, 2010). In addition, perceived level of trust between the parties, their commitment to the relationship and the level of interaction between them are vital for an efficient risk management process (Iakovou et al., 2009).

Based on Pfohl et al. (2008), the risks for shippers induced by LSPs in sourcing and distribution are not seen as critical. More important for shippers are, in contrast, the external catastrophic risks, and as most of these events (especially natural disasters) will also have an impact on the LSP they should be considered together with the LSP in a joint SCRM. Only limited research was performed on potential strategies for shippers to reduce their risk exposure by using LSPs. Sodhi and C.S. Tang (2012) and Iakovou et al. (2009) describe flexible transportation (i.e. multiple routes, multimodal and multi-carrier transportation) as a robust supply chain strategy to increase the flexibility in case of a disruption. Further strategies are shown in Table 4.

5 Framework of logistics outsourcing as risk management strategy

As the findings in the previous chapters show, logistics outsourcing is on the one hand increasingly used to reap the benefits but on the other hand can increase the vulnerability of the supply chain, an especially dangerous situation with increasing disruptions expected. The effect of logistics outsourcing in the SCRM of shippers is influenced by certain factors, which are depicted in the below overall framework (refer to Figure 5). This framework is focused on the effect logistics outsourcing has compared to the internal provision of logistics services and therefore it can only be a part of an integrated risk management strategy of the company in focus.

Figure 5: Supply Chain Vulnerability Framework of Logistics Outsourcing



The complexity of services offered by LSPs is increasing (refer to Chapter 2) and each offering may have different effects on the vulnerability. To reflect the characteristics of the different services on the one hand and to avoid a too complex framework on the other hand, we included three categories: Transportation (including road, sea, air, rail), warehousing and value-added service (including amongst others quality control, pre-assembly, reverse logistics). As shown in Chapter 4.2 the outsourcing of logistics can have either a positive or negative aspect on the vulnerability of the shipper. Therefore we distinguish the two contrasting effects in the framework by showing it as one dimension with positive and negative impact on the vertical axis. The position on the axis however does not indicate a stronger or weaker effect of the mentioned elements.

The enablers of a well-functioning SCRM between shipper and LSP are comparable to the prerequisites for SCM, but also entail certain logistics-related elements. To what extend each of the enablers are required or feasible also depends on the relationship between shipper and LSP. This may vary from an arm's length relationship to a collaborative approach (refer to Chapter 2), which often correlates with the scope of service covered (Bask, 2001). However, this may not always be the case and the effect on the vulnerability can be ambiguous (e.g. an arm's length relationship may decrease the vulnerability as the shipper can easily switch, but on the other hand the limited compatibility of the IT systems may increase the vulnerability).

Whether logistics outsourcing can actually increase or decrease the vulnerability depends also to a certain degree on the shipper's supply chain characteristics. An LSP with an international network of air, sea and road transport can decrease the supply chain vulnerability of a global shipper, but may have only limited effect for a shipper with only national or even regional supply and demand.

6 Future Research and Conclusion

Both research streams, SCRM and outsourcing of logistics, are still at a nascent stage (Jüttner, 2005; Jüttner et al., 2003; Selviaridis and Spring, 2007; Sodhi et al., 2012; Wagner and Bode, 2008), making future research important for academia as well as practitioners. However, the linkage of these two increasingly relevant topics seems not to have attracted considerable attention from a research point of view so far, as our literature review points out. However, the interrelation of SCRM and logistics is seen as important (Norrman and Jansson, 2004).

The integrity of the developed framework of logistics outsourcing can be tested by e.g. survey or case studies, addressing shippers and LSPs. Furthermore, the relevance of this topic and the active use in practice may also be investigated. Previous work by Pfohl et al. (2008) indicate that LSPs are not seen as a critical risk source, but it hasn't been investigated whether they can mitigate risks. As a result, the model may be extended or updated.

Furthermore, the elements of the framework may be e.g. rated by shippers in a survey to determine the strength of the effect on the vulnerability. Thus the current positioning in the framework, which does not indicate the strength, can be updated. In addition, the effect of the enablers as well as the supply chain characteristics and the degree of collaboration on the elements of the framework may be researched. All this may be helpful for practitioners to define their supply chain strategy (e.g. changing certain supply chain characteristics) or the type of collaboration with their LSP (e.g. using certain enablers and changing the type of relationship) to further improve their SCRM.

The review of existing literature, the development of a conceptual framework and the stated initial suggestions for future research give an impulse for researchers to explore this field further for mutual benefits. However, due to the early status of this nascent field, a broad range of possibilities exists, which cannot be detailed out here in full.

The topic of increasing risks in supply chains is not new for practitioners; however the importance of logistics in the context of risk management has been underestimated in the past (Christopher and Lee, 2004; Peck, 2006; Solakivi et al., 2011) and the confidence in the risk management capabilities of LSPs is still low (Langley and Capgemini, 2012a). The increasing trend of logistics outsourcing is stimulating the need to collaborate with LSPs in SCRM to improve the robustness or resilience of the supply chain. Thus, it should be put on top of the agenda of senior executives. Shippers should review not only their own SCRM, but critically challenge also the SCRM of their suppliers and the critical link to the LSP to ensure a working system in case of a future disruption. Practitioners should better be prepared and put their efforts into this topic to keep the competitive advantage of their companies also in turbulent times.

7 References

Andersson, D. and Norrman, A. (2003), "Managing risks when outsourcing advanced logistics", *12th International IPSERA Conference*, pp. 377–391.

Andersson, D. and Norrman, A. (2004), "Outsourcing advanced logistics: A shipper's and provider's perspective on risks", in Brindley, C. (Ed.),*Supply Chain Risk*, Ashgate Pub Ltd, Hampshire, UK, pp. 160–174.

Ansari, A. and Modarress, B. (2010), "Challenges of outsourcing logistics to third-party providers", *International Journal of Logistics Systems and Management*, Vol. 7 No. 2, pp. 198–218.

Ashenbaum, B., Maltz, A. and Rabinovich, E. (2005), "Studies of Trends in Third-Party Logistics Usage: What Can We Conclude?", *Transportation Journal*, Vol. 44 No. 3, pp. 39–50.

Bask, A.H. (2001), "Relationships among TPL providers and members of supply chains – a strategic perspective", *Journal of Business & Industrial Marketing*, Vol. 16 No. 6, pp. 470–486.

BBC. (2010,April20), "Iceland volcano: Nissan and BMW suspend some production", *BBC News*. Retrieved July 13, 2012, from http://news.bbc.co.uk/1/hi/business/8631676.stm

Bowersox, D.J. (1990), "The strategic benefits of logistics alliances", *Harvard Business Review*, Vol. July-Augus, pp. 36–45.

Burt, D.N., Dobler, D.W. and Starling, S.L. (2003), *World Class Supply Management: The Key to Supply Chain Management*, McGraw Hill, Boston, 7thed.

Chopra, S. and Meindl, P. (2009), *Supply Chain Management*, Prentice Hall International, New Jersey, 4thed.

Christopher, M. (2011), *Logistics and Supply Chain Management*, FT Press, 4thed.

Christopher, M. and Lee, H. (2004), "Mitigating supply chain risk through improved confidence", *International Journal of Physical Distribution & Logistics Management*, Vol. 34 No. 5, pp. 388–396.

Christopher, M. and Peck, H. (2004), "Building the resilient supply chain", *International Journal of Logistics Management*, Vol. 15 No. 2, pp. 1–13.

Christopher, M. and Ryals, L. (1999), "Supply chain strategy: its impact on shareholder value", *International Journal of Logistics Management*, Vol. 10 No. 1, pp. 1–10.

Crone, M. (2006), "Are global supply chains too risky? a practitioner's perspective", *Supply Chain Management Review*, Vol. 10 No. 4, pp. 28–35.

DHL. (2010), “Effect of Icelandic volcano cloud”, *DHL Financial Newsletter*. Retrieved July 2, 2012, from http://www.dp-dhl.com/en/media_relations/abonnements/financial_media_newsletter/background_q1_2010.html

Fawcett, S.E., Birou, L. and Taylor, B.C. (1993), “Supporting global operations through logistics and purchasing”, *International Journal of Physical Distribution & Logistics Management*, Vol. 23 No. 4, pp. 3–11.

Gentry, J.J. (1993), “Strategic Alliances in Purchasing: Transportation Is the Vital Link”, *International Journal of Purchasing and Materials Management*, Vol. 29 No. 3, pp. 11–17.

Hendricks, K.B. and Singhal, V.R. (2003), “The effect of supply chain glitches on shareholder wealth”, *Journal of Operations Management*, Vol. 21 No. 5, pp. 501–522.

Hendricks, K.B. and Singhal, V.R. (2005a), “An Empirical Analysis of the Effect of Supply Chain Disruptions on Long-Run Stock Price Performance and Equity Risk of the Firm”, *Production and Operations Management*, Vol. 14 No. 1, pp. 35–52.

Hendricks, K.B. and Singhal, V.R. (2005b), “Association Between Supply Chain Glitches and Operating Performance”, *Management Science,* Vol. 51 No. 5, pp. 695–711.

Husdal, J. (2009), “Does location matter? Supply chain disruptions in sparse transportation networks”, *TRB Annual Meeting 2009*, Washington D.C.

Huth, M. and Lohre, D. (2009), *Risikomanagement in der Speditions- und Logistikbranche – Bestandsaufnahme zu Verbreitung und Reifegrad*, Frankfurt am Main.

Iakovou, E., Vlachos, D. and Xanthopoulos, A. (2009), “Risk and Security Management for Logistics Service Providers: Trends, Challenges, and Opportunities”, in Wagner, S.M. and Bode, C. (Eds.),*Managing Risk and Security: The Safeguard of Long-Term Success for Logistics Service Providers*, Haupt Publisher, 1sted., pp. 59–81.

Janvier-James, A.M. (2012), “A New Introduction to Supply Chains and Supply Chain Management: Definitions and Theories Perspective”, *International Business Research*, Vol. 5 No. 1, pp. 194–207.

Jüttner, U. (2005), “Supply chain risk management: Understanding the business requirements from a practitioner perspective”, *International Journal of Logistics Management*, Vol. 16 No. 1, pp. 120–141.

Jüttner, U., Peck, H. and Christopher, M. (2003), “Supply Chain Risk Management: Outlining an Agenda for Future Research”, *International Journal of Logistics Research and Applications*, Vol. 6 No. 4, pp. 197–210.

Kersten, W., Hohrath, P. and Winter, M. (2008), “Risikomanagement in Wertschöpfungsnetzwerken - Status Quo und aktuelle Herausforderungen”, *Wirtschaft und Management: schriftenreihe zur wirtschaftswissenschaftlichen Forschung und Praxis,* Fachhochschule des bfi Wien, Band 8., pp. 7–21.

Khan, O. and Burnes, B. (2007), "Risk and supply chain management: creating a research agenda", *International Journal of Logistics Management*, Vol. 18 No. 2, pp. 197–216.

Kleindorfer, P.R. and Saad, G.H. (2005), "Managing Disruption Risks in Supply Chains", *Production and Operations Management*, Vol. 14 No. 1, pp. 53–68.

Van Laarhoven, P., Berglund, M. and Peters, M. (2000), "Third-party logistics in Europe–five years later", *International Journal of Physical Distribution & Logistics Management*, Vol. 30 No. 5, pp. 425–442.

Lalonde, B.J. and Cooper, M.C. (1989), *Partnerships in Providing Customer Service: A Third-Party Perspective*, Council of Logistics Management, Oak Brook, IL, USA.

Lambert, D.M., Emmelhainz, M.A., Gardner, J.T. and Gardner, E. (1999), "Building successful logistics partnerships", *Journal of Business Logistics*, Vol. 20 No. 1, pp. 165–181.

Langley, C.J. and Capgemini. (2012a), *2012 Third-Party Logistics Study*.

Langley, C.J. and Capgemini. (2012b), *2013 Third-Party Logistics Study*.

Lieb, R.C., Millen, R.A. and Van Wassenhove, L.N. (1993), "Third-party logistics: A comparison of experienced American and European manufacturers", *International Journal of Physical Distribution & Logistics Management*, Vol. 26 No. 3, pp. 35–44.

Maloni, M.J. and Carter, C.R. (2006), "Opportunities for Research in Third-Party Logistics", *Transportation Journal*, Vol. 45 No. 2, pp. 23–38.

Maltz, A. and Ellram, L.M. (1997), "Total cost of relationship: An analytical framework for the logistics outsourcing decision", *Journal of Business Logistics*, Vol. 18 No. 1, pp. 45–66.

March, J.J. and Shapira, Z. (1987), "Managerial perspectives on risk and risk taking", *Management science*, Vol. 33 No. 11.

Melnyk, S.A., Lummus, R., Vokurka, R.J. and Sandor, J. (2006), *Supply Chain Management 2010 and Beyond: Mapping the Future of the Strategic Supply Chain*, East Lansing, MI.

MunichRe. (2012), *Great natural disasters since 1950*, Munich.

Naim, M.M., Aryee, G. and Potter, A. (2010), "Determining a logistics provider's flexibility capability", *International Journal of Production Economics*, Elsevier, Vol. 127 No. 1, pp. 39–45.

Norrman, A. and Jansson, U. (2004), "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident", *International Journal of Physical Distribution & Logistics Management*, Vol. 34 No. 5, pp. 434–456.

O'Marah, K. and Afghan, F. (2011), *Value Chain Ecosystems of the Future The Role of Outsourcing in Supply Chain Strategy*.

Ogden, J.A., Petersen, K.J., Carter, J.R. and Monczka, R.M. (2005), "Supply Management Strategies for the Future: A Delphi Study", *Journal of Supply Chain Management*, Vol. 41 No. 3, pp. 29–48.

Ojha, D. and Gokhale, R. a. (2009), "Logistical business continuity planning-scale development and validation", *International Journal of Logistics Management*, Vol. 20 No. 3, pp. 342–359.

Oxford Economics. (2010), *The Economic Impacts of Air Travel Restrictions Due to Volcanic Ash*, Oxford.

Peck, H. (2006), "Reconciling supply chain vulnerability, risk and supply chain management", *International Journal of Logistics: Research and Applications*, Vol. 9 No. 2, pp. 127–142.

Pfohl, H.-C., Gallus, P. and Köhler, H. (2008), "Risikomanagement in der Supply Chain - Status Quo und Herausforderungen aus Industrie-, Handels- und Dienstleisterperspektive", in Pfohl, H.-C. (Ed.),*Sicherheit und Risikomanagement in der Supply Chain*, pp. 95–147.

Pfohl, H.-C., Köhler, H. and Thomas, D. (2010), "State of the art in supply chain risk management research: empirical and conceptual findings and a roadmap for the implementation in practice", *Logistics Research*, Vol. 2 No. 1, pp. 33–44.

PWC. (2011), *Transportation & Logistics 2030 Volume 4: Securing the supply chain*, Vol. 4.

PWC. (2012), *Risk-Management Benchmarking 2011/12*.

Rao, S. and Goldsby, T.J. (2009), "Supply chain risks: a review and typology", *International Journal of Logistics Management*, Vol. 20 No. 1, pp. 97–123.

Razzaque, M.A. and Sheng, C.C. (1998), "Outsourcing of logistics functions: a literature survey", *International Journal of Physical Distribution & Logistics Management*, Vol. 28 No. 2, pp. 89–107.

Richardson, H.L. (1995), "Logistics help for the challenged", *Transportation & Distribution*, Vol. 36 No. 1.

Sanchez-Rodrigues, V., Potter, A. and Naim, M.M. (2010), "Evaluating the causes of uncertainty in logistics operations", *The International Journal of Logistics Management*, Vol. 21 No. 1, pp. 45–64.

Sanchez-Rodrigues, V., Stantchev, D., Potter, A., Naim, M.M. and Whiteing, A. (2008), "Establishing a transport operation focused uncertainty model for the supply chain", *International Journal of Physical Distribution & Logistics Management*, Vol. 38 No. 5, pp. 388–411.

Selviaridis, K. and Spring, M. (2007), "Third party logistics: a literature review and research agenda", *International Journal of Logistics Management*, Vol. 18 No. 1, pp. 125–150.

Sheffi, Y. and Rice, J.B. (2005), “A supply chain view of the resilient enterprise”, *MIT Sloan Management Review*, Vol. 47 No. 1, pp. 41–48.

Sheffi, Y., Rice, J.B., Caniato, F., Fleck, J., Disraelly, D., Lowtan, D., Lensing, R., et al. (2003), *Supply Chain Response to Terrorism: Creating Resilient and Secure Supply Chains*, Cambridge, MA.

Siebrandt, M. (2010), *Professionelles Risikomanagement in der Logistik*, DVL, Hamburg.

Skjoett-Larsen, T. (2000), “Third party logistics - from an interorganizational point of view”, *International Journal of Physical Distribution & Logistics Management*, Vol. 30 No. 2, pp. 112–127.

Sodhi, M.S., Son, B.-G. and Tang, C.S. (2012), “Researchers’ Perspectives on Supply Chain Risk Management”, *Production and Operations Management*, Vol. 21 No. 1, pp. 1–13.

Sodhi, M.S. and Tang, C.S. (2012), “Strategic Approaches for Mitigating Supply Chain Risks”, *Managing Supply Chain Risk*, Springer, Boston, MA, Vol. 172, pp. 95–108.

Solakivi, T., Töyli, J., Engblom, J. and Ojala, L. (2011), “Logistics outsourcing and company performance of SMEs: Evidence from 223 firms operating in Finland”, *Strategic Outsourcing: An International Journal*, Vol. 4 No. 2, pp. 131–151.

Spekman, R.E. and Davis, E.W. (2004), “Risky business: expanding the discussion on risk and the extended enterprise”, *International Journal of Physical Distribution & Logistics Management*, Vol. 34 No. 5, pp. 414–433.

Sullivan, J.L., Aultman-Hall, L. and Novak, D.C. (2009), “A review of current practice in network disruption analysis and an assessment of the ability to account for isolating links in transportation networks”, *Transportation Letters: The International Journal of Transportation Research*, Vol. 1 No. 4, pp. 271–280.

Ta, C., Goodchild, A. V. and Pitera, K. (2009), “Structuring a Definition of Resilience for the Freight Transportation System”, *Transportation Research Record*, Vol. 2097, pp. 19–25.

Tang, C.S. (2006), “Perspectives in supply chain risk management”, *International Journal of Production Economics*, Vol. 103 No. 2, pp. 451–488.

Tang, O. and Nurmaya Musa, S. (2011), “Identifying risk issues and research advancements in supply chain risk management”, *International Journal of Production Economics*, Elsevier, Vol. 133 No. 1, pp. 25–34.

Wagner, S.M. and Bode, C. (2006), “An empirical investigation into supply chain vulnerability”, *Journal of Purchasing and Supply Management*, Vol. 12 No. 6, pp. 301–312.

Wagner, S.M. and Bode, C. (2007), “Empirische Untersuchung von SC-Risiken und SC-Risikomanagement in Deutschland”, in Vahrenkamp, R. and Siepermann, C. (Eds.),*Risikomanagement in Supply Chains - Gefahren abwehren, Chancen nutzen, Erfolg generieren*, Berlin, pp. 59–79.

Wagner, S.M. and Bode, C. (2008), “An empirical examination of supply chain performance along several dimensions of risk”, *Journal of Business Logistics*, Vol. 29 No. 1, pp. 307–XII.

Wagner, S.M. and Bode, C. (2009), *Managing Risk and Security: The Safeguard of Long-Term Success for Logistics Service Providers*, (Wagner, S.M. and Bode, C.,Eds.), Haupt Verlag.

Waters, C.D.J. (2011), *Supply Chain Risk Managament: vulnerability and resilience in logistics*, Kogan Page, London, 2nded.

World Economic Forum. (2012), *Outlook on the Logistics & Supply Chain Industry 2012 Global Agenda*, Geneva, Switzerland.

Zacharia, Z.G., Sanders, N.R. and Nix, N.W. (2011), “The Emerging Role of the Third-Party Logistics Provider (3PL) as an Orchestrator”, *Journal of Business Logistics*, Vol. 32 No. 1, pp. 40–54.

Zsidisin, G.A., Melnyk, S.A. and Ragatz, G.L. (2005), “An institutional theory perspective of business continuity planning for purchasing and supply management”, *International Journal of Production Research*, Vol. 43 No. 16, pp. 3401–3420.

Zsidisin, G.A., Ragatz, G.L. and Melnyk, S.A. (2005), “The dark side of supply chain management”, *Supply Chain Management Review*, Vol. 9 No. 2, pp. 46–52.

Servitizing manufacturers:
The impact of service complexity and contractual and relational capabilities

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Abstract

Servitization drives manufacturing firms to develop service offerings characterised by increasing levels of complexity. This has also been termed service ladder or transformation staircase. Manufacturing companies need to adapt their organisational processes to the different stages of the service ladder to provide value to their customers. In particular, this paper focuses on contractual and relational capabilities for services of different complexities. Based on two case studies within the European Healthcare sector, we found that in a highly regulated business context, contractual capabilities only marginally differ depending on service complexity. In contrast, the importance of relational capability increases with higher levels of service complexity. Developing relational capabilities can function as a competitive advantage for manufactures moving into product-service system offerings.

Keywords: servitization, service complexity, product-service system, contract and relational capabilities, multiple case studies

1. Introduction

In order to stay competitive globally, manufacturing companies have increasingly bundled their products and services to add value to their core offerings (Spring and Araujo, 2009). This change is associated with a shift in focus from individual products or services to the provision of product-service systems (PSSs) (Mont, 2000). PSSs are integrated offerings that consist of a bundle of products, services and information, seamlessly combined to provide and address clients' needs in order to provide more value than the parts alone (Baines et al., 2009). Selling and purchasing PSSs confronts organisations with the challenge of developing and implementing new PSS strategies and associated organisational structures and capabilities. In particular, manufacturers have to develop and implement contractual and relational capabilities.

Servitization is connected to increasing levels of service complexity as different service offerings can have different levels of complexity depending on the company's strategy and capabilities (Neely et al., 2011). For instance, offering support services such as maintenance incorporates a lower level of service complexity connected to the operational processes and delivery system than offering outcome-based contracts such as the delivery of product capability. These different levels have been described as a service ladder (Neely et al., 2011) or transformation staircase (House of Commons Defence Committee, 2009). However, the current literature offers limited insights into the issue of service complexity and relationship management in terms of contractual and relational capabilities for PSS providers and customers. In particular, the following two issues are still not well understood. First, limited research explores a dyadic perspective between service provider and customer as many current studies adopt a purely seller perspective. As the value of PSS offerings emerges during their use, it is the dyadic relationship that plays a key role in determining the benefit. Second, prior studies do mainly not distinguish between different levels of service complexity (except Neely et al., 2011) and their impact on contractual and relational capabilities.

We address the above limitations by answering the following two research questions (RQs): (i) To what extent do different levels of service complexity impact on contractual capabilities when providing and buying PSSs?; (ii) To what extent do different levels of service complexity impact on relational capabilities when providing and buying PSSs? We investigate the RQs by presenting two case studies of one PSS provider and its customers. The studied provider operates in the European healthcare sector and has traditionally been a manufacturer of complex engineering products and has made deliberate steps to introduce servitization strategies based on PSSs. The presented case studies offered an in-depth understanding of contractual and relational capabilities in an organisational context to compare the influence of service complexity. Thus, we contribute to the literature in the field in two ways. First, the investigation of both PSS provider and customer offers insights into the service relationship from a dyadic perspective which helps to draw a more comprehensive picture of the PSS and relationship management. Second, we offer a theoretically-grounded and empirically-tested framework of service complexity in the context of servitization and its influence on contractual and relational capabilities. This will form a guideline for industry to strategically plan and develop their service offerings and the necessary contractual and relational capabilities.

2. Theoretical background

2.1 Service complexity and servitization

The typical offerings described in the servitization literature are Product Service Systems (PSS). PSSs are integrated, seamless combinations of products, services and information (Baines et al., 2009). They are often described as integrated solutions (Davies et al., 2006) that create value by improving operating efficiency, increasing asset effectiveness, enabling market expansion, and mitigating risk (Cornet et al., 2000). The shift towards providing and receiving PSSs is typically undertaken gradually (Smith et al., 2012). In other words, manufacturing companies provide support services with different degrees of orientation around the product. These offerings include different levels of service complexity (Batista et al., 2008). Complexity in the context of services can have varying definitions depending on their focus (Neely et al., 2011). Reviewing the literature in the field, Benedettini and Neely (2011; 2012) found that service complexity can be differentiated into complicatedness and difficulty. Complicatedness refers to the high number of components and their interrelation within the service provision. Difficulty is defined as the high amount of resources that are needed to achieve the intended outcome. In other words, a complicated service offers many different functions while a difficult service delivers sophisticated functions (Benedettini and Neely, 2012). However, this does not seem to be a distinct differentiation as a service that delivers sophisticated functions often also delivers many different functions. As such, complexity can be connected to the engineering system necessary to fulfill the requirements (Ng et al., 2011) and the interaction between the service stakeholders (Tien, 2008). Complexity can further arise from the dynamic nature of services due to the 'open' nature of services, i.e. the constant adaptation to context and conditions (Badinelli et al., 2012).

In this paper, we use a definition of complexity associated with the characteristic of the services. As such, we do not relate our understanding of service complexity to the amount and interaction of the people involved in the production and consumption of a service (Tien, 2008) or the dynamic change of the service to adapt to new situations and conditions (Badinelli et al., 2012). We agree that these are important aspects that can create complexity and need to be considered in a coherent understanding of this topic. However, the purpose of this paper is to draw the connection between service complexity and contractual and relational capabilities and thus we use a more static characterisation of service complexity. This was captured in Shostack's definition which says that complexity is *"the number and intricacy of the steps required to perform it"* (1987: 35). This definition relates to the service system used in the literature (Ng et al., 2011) and seems to also incorporate both categories of service complexity presented by Benedettini and Neely (2011; 2012). It further highlights the activity-centered process of services (Araujo and Spring, 2006).

The assumption is that the path towards offering PSSs is connected to an increasing level of service complexity. The shift towards providing and receiving PSSs means that the activities and processes of provider and customer become increasingly integrated which has also been described as a service ladder (Neely et al., 2011) or transformation staircase (House of Commons Defence Committee, 2009). Processes relate to information sharing, planning and undertaking of the activities to deliver the availability of a range of products (Tukker, 2004; Neely et al., 2011). The higher the level of integration, the more activities and processes are necessary to provide and receive the PSS, i.e. the higher the service complexity. This is the assumption underlying the research presented in this paper and is depicted in **Figure 1**.

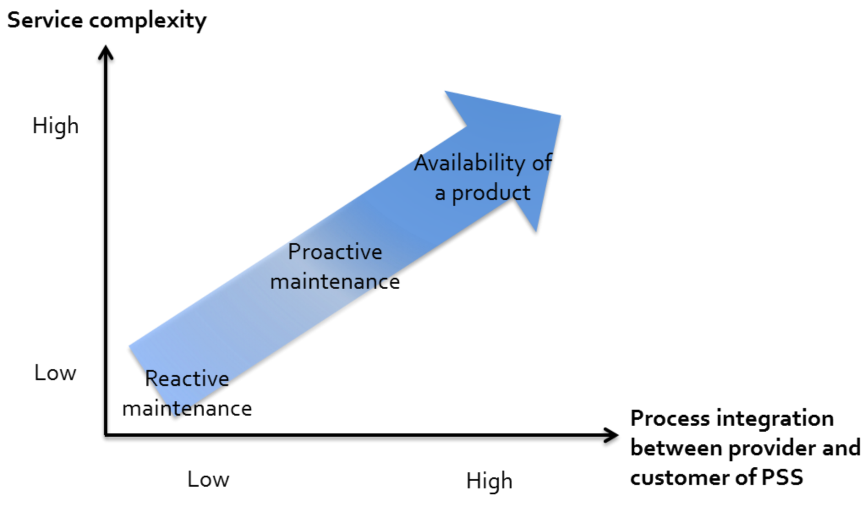

Figure 1. Relationship between service complexity and process integration between provider and customer of PSS

2.2 Capability development for PSS delivery

The extant body of literature on capabilities has emphasised how organisations must possess the relevant resources, knowledge and skills to create or adapt to new market and technological opportunities (Teece et al., 1997). A capability is the ability of the organisation to perform coordinated activities utilising resources to achieve a goal and to purposefully create, extend or modify its resource base (Helfat and Peteraf, 2003). Zollo and Winter (2002) claim that capability development is often initiated by an external stimuli or feedback such as a need to transition towards PSS offerings. The heterogeneity of capabilities across organisations then is a reflection of different investments of time, efforts and resources in these learning activities (Zollo and Winter, 2002). To provide PSS arrangements, organisations need to restructure their product-service delivery by establishing new contractual and relational capabilities. With regards to relationship management to deliver PSS offerings, the following sections review two discrete, yet inter-related, types capabilities: contractual and relational.

2.2.1 Contractual capabilities

Contractual capabilities refer to the recognition of the contingencies associated with PSS offerings and their implications for the efficiency and effectiveness of the service delivery, encompassing capabilities to write, negotiate, monitor and enforce contracts (Mayer and Argyres, 2004). Contractual safeguards and rules are established to minimise cost and performance losses from relationship hazards (Joskow, 1988). In other words, PSS suppliers and buyers structure complex contracts to protect themselves from opportunistic behaviour, to reduce uncertainties and to specify roles and responsibilities of partnering organisations by relying upon legal rules, standards and remedies (Achrol and Gundlach, 1999). The study by Deakin et al. (1997) draws out the importance of contracts as a planning and incentivisation tool in long-term business relationships. According to TCE logic, the most efficient legal safeguard represents a trade-off between different instruments of formal control, depending on the degree of asset specificity, uncertainty and transaction frequency (Williamson, 1985). Complete contracts reduce uncertainty, risk of opportunism and provide a safeguard against ex post performance problems (Williamson, 1985).

Bijlsma-Frankema and Costa (2005) argue that formal control through contracts depends on three underlining conditions – codification, monitoring and safeguards - which are seldom fulfilled in an inter-organisational relationship. In practice it is rarely possible or practical to draft complete contracts owing to the complex nature of product-service offerings, asymmetric information situations and associated costs and time efforts (Lyons and Mehta, 1997). Inter-organisational relationships are mostly governed by incomplete contracts with an element of uncertainty that makes them unenforceable in their entirety (Roehrich and Lewis, 2010). Gaps in the existing contract are filled when contingencies arise, allowing some degree of flexibility to deal with unforeseen contingencies (Klein Woolthuis et al., 2005).

2.2.2 Relational capability

Relational capabilities are an organisation's ability to benefit from its inter-organisational relationships (Bititci et al., 2003). In other words, relationally capable organisations invest in relationship-specific assets and effectively create, exchange and exploit knowledge and skills through the application of socially complex routines. Thus, relational capabilities refer to socially complex routines, procedures and policies in inter-organisational relationships which are vital to establish and maintain through inter-personal and inter-organisational trust (Zaheer et al., 1998). Partnering companies invest in relationship-specific assets and create exchange knowledge and effectively govern their relationship through relational routines and behaviour (Dyer and Singh, 1998). Contractual capabilities are complemented by relational capabilities to prevent conflicts and adversarial behaviour and to promote problem-solving and information exchange (Carey et al., 2011).

The concept of relational capabilities draws on related concepts such as learning (Zollo and Winter, 2002), alliance competence (Gemünden and Ritter, 1997), interaction capability (Capaldo, 2007), relational capital and administrative mechanisms providing institutional support (Sivadas and Dwyer, 2000). Although relational dynamic capabilities are a significant trend in the future of strategic research, their foundations are still in their infancy and their investigation is fragmented. A few recent contributions have used empirical approaches and moved beyond abstract concepts to focus on practices, functions, tools and controls (Roehrich and Lewis, 2010). Prior research on relational capability development explored the concepts in alliances and supply chain processes in long-term relationships (Dyer and Singh, 1998).

2.3 Positioning an initial conceptual framework

Relating the development of contractual and relational capabilities in PSS relationships to the issue of service complexity, we position an initial conceptual framework as depicted in Figure 2. We expect that higher levels of service complexity will need to be supported by a higher amount of contractual and relational capabilities in order to coordinate between the PSS provider and itscustomers.

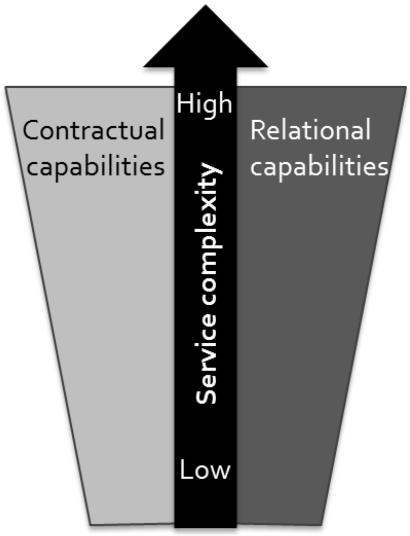

Figure 2. Initial conceptual framework

3. Methodology

3.1 Research approach and case selection

To investigate the research questions: (i) To what extent do different levels of service complexity impact on contractual capabilities when providing and buying PSSs?; (ii) To what extent do different levels of service complexity impact on relational capabilities when providing and buying PSSs?, we present two case studies of different levels of service complexity within one company to gather an in-depth understanding of the issue (Stake, 1995; Yin, 2009). Our case company, which we label 'PSS provider', operates within the European healthcare industry and offers support services for their equipment. The company's service offers can be categorised into three levels which differed mainly in their level of service complexity. These three levels are described in Table 1. For this study, we selected an agreement from level 1 (case A) and from level 3 (case B) to compare and contrast the impact of service complexity on the development of contractual and relational capabilities.

Table 1. Service offerings of PSS provider

Service level	Complexity	Description
1	Low	Proactive preventative maintenance by the supplier to ensure safe and efficient operation of the products. This includes documented inspections, quality assurance, security inspections and software inspections for viruses or similar.
2	Medium	All the activities included in level 1 plus labour rates for corrective maintenance activities, telephone support and regular updates of the equipment.
3	High	The availability of the product is guaranteed by delivering maintenance (both preventative and corrective maintenance activities), delivery of spare parts, regular updates of the software systems to enhance productivity and availability

3.2 Data collection and analysis

Our unit of analysis is the PSS, encompassing contractual and relational capability developments within two service agreements between the case company and two of their customers. The customers were hospitals providing different health services to private patients. In 2013, we conducted 23 semi-structured interviews with 19 interviewees both on the provider and customer sides to obtain insights from 'both sides of the story' (some of the interviewees from the PSS provider side were interviewed for both cases). The interviews addressed retrospective and current activities of the service agreements. Respondents were drawn from multiple functions, such as service managers, account managers, service engineers, strategic buyers and physicians who were involved in the servie agreement and stood in direct relationship with the customer or PSS provider. We asked questions about the rationale for moving to PSS offerings, changes in the organisational strategy and structure, the development of the dyadic relationship and the importance and development of contractual and relational capabilities. Interviews lasted between 45 and 120 minutes and were tape-recorded and sub-sequently transcribed. Data collection stopped when we experienced conceptual saturation. We triangulated data to overcome common method bias and improve internal and external validity and case study rigour (Lewis and Grimes, 1999).This included the service contracts, information on the tendering process, marketing material and other publicly available information such as announcements on webpages.

We analysed the interview transcripts and the additional material, adopting 'systematic combining' to inform our analysis of the data (Dubois and Gadde, 2002). In other words, we drew on existing theory and aimed to generate justified research questions, analysis and implications with regards to causal drivers for PSS and capability developments and changes. We systematically coded our data into major thematic categories connected to PSS, relational and contracual capabilities (Strauss and Corbin, 1990). Some categories were derived from our theoretical framing while others emerged based on our empirical data analysis. Data were subsequently summarised and written up as case reports to be presented to the case companies for verification. Data were coded, summarised and displayed in an iterative fashion – travelling back and forth between data analysis, data collection and pertinent literature – and facilitated theory building (Miles and Huberman, 1994).

4. Findings

Both contracts were based on a long-standing relationship between the PSS provider and two customers. However, the interviews highlighted that this relationship changed driven by the change of the business context. We describe the context for the PSS relationship before highlighting findings with regards to contractual and relational capabilities.

4.1 Contextual setting

The business conditions and contextual setting of the European healthcare sector have changed dramatically over recent decades. The process of acquiring new equipment and new service agreements has been formalised with the introduction of a formal European-wide tendering process. This means that the customer have to publish their requirements with detailed descriptions of the required service complexity and requested service activities. This process also means that communication between the customer and the competing PSS providers (i.e. bidders) is also formalised. For instance, questions regarding the service requirements or contractual arrangements can be asked but tend to be communicated to all competing PSS providers. Informal communications or exchange are constraint by these tendering regulations. All of the submitted bids are evaluated objectively based on predefined and published criteria. These criteria are usually price bid (including the price of the equipment, education of the customer's staff and the Total Cost of Ownership), degree of fulfilment of the requirements, performance and workflow.). The service manager (both cases) expressed his evaluation of the changing business context as follows;

> *"They have changed a lot. If you look at the sales for instance, in the old days it was the relationship between one customer and one sale engineer. That was the most important part from the sales. Right now you have the tender business that means that everybody from the EU can go in and make an offer when they announce the tenders. We are all evaluated objectively. That means the relations are not there at all on the paper. But of course in the real world, there are of course some relations that are still working. But not as it used to be."* (Service Manager, PSS provider)

One implication of this formalisation of the tendering and negotiating process is that the acquisition process has become longer and more complex. Simple requirements and acquisition of equipment cannot be solved within this "relationship between one customer and one sale engineer" (Service manager, PSS provider, both cases). In contrast, a formal list of requirements has to be compiled for each acquisition which needs to follow rigid European legal guidelines and laws. This means that the acquisition process has changed from agreements between two companies or even between a sales engineer and his/her customer to a more substantial process with legal implications. One of the physicists of case B explaines: *"It tends to be quite substantive. The work load and so on. You almost need to have a legal department nowadays to handle these things"* (Physicist 2, customer, case B).

This means that the tenders now mainly aggregate service offerings into larger contracts. "If you win, you win a lot. If you lose, you lose a lot. It is important to win because you can actually lose a whole region just in one tender" (Account manager, PSS provider, case B). This has put a lot of pressure on the PSS provider to win the tenders when they are announced. In particular, the PSS providers had to adapt to the changes as the tendering process had become more strenuous and more complex. These organisational adaptations happened abruptly through the introduction of the tendering process and were long lasting with effects still visible to date. For the first tender, the PSS provider had to prepare a service agreement for 20 products in addition to bids for three other product ranges. The Service Manager explained:

> *"Four offers at once in a big pile. Nobody had summer vacation that year; everybody worked 24 h a day until we could deliver our offers. And you could say 'That was tough.' But it created that burning platform for us that meant, in fact, that we made some things that we are still using today. So that was kind of a shift we made through that one (tender)."* (Service Manager, PSS provider, both cases)

In addition, the PSS provider expressed concerns that their customers had become increasingly demanding with regards to the service offerings. As such, customers demand new business models that do not only include the product but also the maintenance and servicing of these products over extended lifecycles. For instance, the Service Manager of the PSS provider (both case) mentioned that: *"The customer asked for higher uptime of the equipment use and then you could not live with the fact that the equipment can be down for 1, 2 or 3 days. That could happen quite often if you do not do proper maintenance and if you do not learn from the past and use this experience to develop solutions that would avoid downtime."* As such, the service components have become vital for the survival of European manufacturers in the healthcare industry. This means that the PSS providers have changed their offerings in accordance with the customer demand to secure additional revenue and secure customers.

4.2 Contractual capabilities

Our assumption of the initial framework was that service agreements of higher complexity will show higher levels of contractual capabilities. One reasons for this assumption was that the additional contractual capabilities would be needed to deal with the additional uncertainties introduced through the additional activities and their interdependencies of services with higher complexity. However, for both cases, only marginal differences in the contractual capabilities were detected. Both contracts consisted of three pages with the following content: (i) a title page that listed the serviced product(s) with its specifications such as product type and model number; (ii) one page describing the service activities. This was done using a modular approach where a table showed the different activities for each of the three levels of service complexity and the ones included in the specific contract were clearly marked.; and (iii) one page of contract specific information such as agreed response time, telephone numbers in case telephone support was part of the agreement, the contract date and the signatures of contractual partners.

In addition, the contract covering the higher level service complexity offering included two additional pages, stating general terms and conditions of the PSS provider. Thus, our assumption of higher levels of contractual capabilities for services of higher levels of complexity was not empiircally supported across our investigated cases. One reason for this could be the high level of regulations within the European healthcare sector. As such, there were tight regulations within the sector that had legal implications by themselves as it prohibits specific opportunistic behaviour . This was explained by the Account Manager (PSS provider) of case B as follows: *"We can't talk together. I can't call the other company [a competitor] and say 'Well, we don't like this one going out in the summer. Why don't we all* *just ignore it?' That's illegal so not possible."* In other words, the legality of possible opportunistic behaviours both on the PSS provider and the customer side is mitigated by European regulations. This means that rules to mitigate opportunistic behaviour do not have to be included in every contract, thus contract complexity has rather been reduced.

The agreement of contract-specific performance indicators was clearly stated from the outset of the tendering process. The Service Manager from the PSS provider (both cases) stated: *"As a result of the tender they [customers] have defined all the service levels. I do not have to tell them what those services are because they decided themselves."* However, the customer's specifications in the tender documents may not completely relate to the service offerings by the PSS provider. Thus, the Service Manager went on to highlight that: *"I then translate their service levels 1, 2, 3, 4, 5, 6 and so on into our service level understanding of [levels 1, 2 and 3]. That is important as I do not want the transparency to be too big. If they, for instance, have a [competitor's] scanner I can directly compare and if it is not the same I put in more modules to match and exceed their [competitor's] service offering."* This statement highlights that despite the high level of regulations in the sector, strategic evaluations and contractual arrangements with the specific PSS providers are still important.

An example of contract-specific indicators was the response time to failures of repair requests from the customer. This was found to be also related to the level of service complexity across the investigated case studies. As such, the contract characterised by a high level of service complexity included a shorter response time in the contract than the contract with low service complexity. The Service Engineer, PSS provider in case A (low complexity) mentioned that: *"We [supplier] are on call so they [buyer] can call us within working hours and we need to address that within 4 hours. We have to take some actions. That has been the purpose of the contract."* In contrast, in case B the PSS provider had to react within one hour of the customer request. The Service Engineer, PSS provider, case B explained: *"The usual procedure will be that if I am just sitting at my office I will go to the customer side, but if I am busy with something else, I will connect remotely and see if I can diagnose the problem."* In summary, the contract with the higher level of service complexity included performance indicators of higher service quality such as response time within the contractual arrangement.

These findings illustrate that even though the contractual capabilities were not a distinguishing feature with regards to different levels of service complexity across the investigated case studies, they were stillessential to ensure a high level of service quality to be delivered throughout the contract period. Contractual capabilities ensured that occurring problems were addressed in a timely manner to avoid any escalation within the PSS provider-customer relationship.

4.3 Relational capabilities

Despite the high level of regulation within the healthcare sector, we found that relational capabilities were important across both case studies. The customer in case B expressed this as follows: *"Personally, I think it's important that when you go out and you buy a new system, you are not allowed to take into consideration your previous experience. But of course somewhere, you always have that in the back of your head."* (Physicist 2, customer, case B). This highlights that the customer's experience with PSS providers is an important influence on their decision during subsequent tendering processes. This importance was also highlighted by the PSS provider: *"For the service, relations are very important. (...) And these relations are built up over years by brilliant work of all the technicians. So it is very important that we have a good foundation from the customer services"* (Service Manager, PSS provider, both cases).

Our assumption of the initial framework was that more relational capability is needed for services characertised by higher complexity. This assumption was confirmed across both case studies. Case A (low service complexity) was characterised by four annual visits for preventative maintenance activities where the system was inspected and recommendations made. For these visits, appointments are agreed with the customer. *"Then we go on site. And we have a protocol that we have to fill out. And we go step-by-step and perform all the things that need to be done"* (Service Engineer, PSS provider, case A). This protocol is sent to the customer with a list of faults or recommendations for repairs and/or upgrades. *"There is a common field that we could fill out. 'We will recommend you do this and that.' Or we can say 'The system has this fault which we have to find a solution to' because like here they have to pay for the spare parts. So it might be that they want to leave this fault and if it is not security or safety, then they can live with that"* (Service Engineer, PSS provider, case A).

In contrast, case B (high complexity) was characterised by a much closer relationship between the service engineers and the customer. When the engineers are on site for the preventative maintenance inspections, they also consider whether there are additional issues they could solve during their visit. Service Engineer 2 in case B explained *"Before getting started, I will ask if they [customer] have any problems that they didn't report to us. Sometimes they have a small problem that they think is not important. They write it in a notebook and they ask me."* In addition, the customer recieves much closer attention even if they do not have any issues with the product. This was highlighted as follows: *"But sometimes I am just going to the customer site and have a chat. To see if they have any problems or just to follow up on how it goes"* (Service Engineer 2, PSS provider, case B). This point was also supported by Service Engineer 1 from case B. This engineer had worked with the customer for 36 years and thus knew the site very well and had a very close relationship with them.

> *"It is always nice to go there. Always when I go there, there are almost all the time some questions that I can look at. Maybe it is not my equipment but also something else, like a PC is not working or something else. It is like I am working in the hospital.(...) Many of them I know personally. Not privately but I have been so many time times they know me and I have 5 km to the hospital. So they just call me. They call me directly"* (Service Engineer 2, PSS provider, case B).

This high level of relational interaction between PSS provider and customer was confirmed by the customer of case B. One of the interviewed physicist explained *"I would say that our relationship with this technician is informal and it works fine for us. (...) I think it worked well if we have a problem we can call (PSS provider) and have a fast and efficient reaction"* (Physicist 1, customer, case B). The second interviewed physician confirmed this: *"The most important thing when you call them they react reasonably quick. They're typically here within an hour; so that is the main thing. And when they come here they solve the problem really fast"* (Physicist 2, customer, case B). This highlights that the customer perceived the realtional capabilities in terms of providing high levels of service quality. They did not comment on the fact that the service engineers of the PSS provider would sometimes be on site without being called in, but they focused mainly on their perception that when they did have a problem, it would be solved quickly and effectively. This suggests that high relational capability was translated by the customer into perceived service quality.

This seemed to also add to the competitiveness of the PSS provider as the service quality, as perceived by the customer, gave them an advantage over competing PSS providers. The fact that local support was available, that the PSS provider had a high level of relational capability already built up, gave the PSS provider a competitive to other PSS providers within the European community. This was highlighted by one of the physicists:

> *"Some of the other manufacturers rely on support from [other European countries] and I think that might be a bit too far away in some cases, when you need to get things up and running quickly. And also the communication might not flow as easily. But that is a good thing with [the PSS provider], they've got quite a huge, local department (...). That is an advantage"* (Physicist 2, customer, case B).

This development of high levels of relational capabilities was part of the operational strategy of the PSS provider. Building a close working relationship between the service engineers and the customer was emphasised as an important aspect that was crucial when, for example, selling additional services in the future.

> *"When we have that [good relations], of course, it is much easier for me to approach the customer because they know our good service. And I do not have to present our organisation, I do not have to present our concept because they know it. In fact, a lot of the service agreements we finalise by mail. I do not visit the customer anymore, we just send an email and they come back to me"* (Service Manager, PSS provider, both cases).

Including the relational capability in the operational and sales strategy of the PSS provider was particularly important for the contract with a high level of service quality. One of the physicists of case B highlighted:

> *"It's nice to know that he's not on the clock. So when he's here, we can actually discuss things and maybe have a cup of coffee. If that wasn't the case, we'd have to stand beside him and watch 'is he working now and is he doing this fast?' It's more relaxed the other way. And then we get the time to discuss other things. (...) I mean if we want to start something new, we can discuss it without worrying about spending [this money]"* (Physicist 2, Customer, Case B).

Thus, our case findings suggest that relational capabilities are influenced by service complexity: The contract with low level of service complexity (case A) showed lower levels of relational capability development than the contract with a high level of service complexity (case B). The following section summarises the results of both cases, reflecting on our initial framework.

5. Discussion

5.1 Contracutal and relational capabilities for PSS relationships

Table 2 summarises the results of both cases with reference to the initial framework. Our initial assumtpions were only partly confirmed through the investigatedcases. Both cases illustrated that contractual capabilities did not differ to a high degree between the two levels of service complexity. One possible reason for this could be the high level of regulation in the industrial sector, as the European healthcare sector is governed by international legal agreements. These regulations include possible opportunistic behaviours of PSS providers and customers. Contractual capabilities are often used to control for these possible opportunistic behaviours, and thus having a high level of regulations means that contractual capabilites can be kept at a low level. Extant literature suggests that the development of contractual capability is particularly important for service agreements as possible opportunistic behaviour can be mitigated, long-term relationships can be established, operational outcomes at agreed performance levels can be guaranteed and competitive advantage can be achieved. However, we showed that in highly regulated business contexts such as the European healthcare industry, high levels of contractual capabilities are not necessary as the regulations deal with these types of uncertainties and possible sources of opportunistic behaviour.

Table 2. Summary of findings of contractual and relational capabilities for contracts of different service complexities

	Low level of service complexity	**High level of service complexity**
Description	Proactive preventative maintenance by the supplier to ensure safe and efficient operation of the products. This includes documented inspections, quality assurance, security inspections and software inspections for viruses or similar.	The availability of the product is guaranteed by delivering maintenance (both preventative and corrective maintenance activities), delivery of spare parts, regular updates of the software systems to enhance productivity and availability.
Contractual capability	Contractual arrangment on three pages including: • Title page with equipment specifications, • Service activities included in the agreement, • Contract specific information including date and signatures.	Contractual arrangment on five pages including: • Title page with equipment specifications, • Service activities included in the agreement, • Contract specific information including date and signatures. • Two pages of terms and conditions form Servie provider.
Relational capability	Importance of relational capability in the service agreement, Low levels of relational capability as every activity and visit needs to be recorded and charged to customer, Formalised information exchange through service protocols	Importance of relational capability in the service agreement, High level of relational capability with regular visits outside of scheduled or requested inspections and repairs, Informal information exchange between PSS provider and customer, Long standing relationship between service engineer and customer, High level of relational capability used for sales strategy

In contrast, relational capabilities were found to be an important mechanism and distinguishing feature even in the existence of high level of regulations. We found that it could influence perceived service quality and future sales. We further found that relational capabilities were dependent on the level of service complexity. For the contract with a high level of service complexity, we detected a high level of relational capability development that was characterised by a close relationship between the service engineer and the customer. In addition, this relationship was characterised by frequent unscheduled visits by the service engineer to the customer site to see whether any additional help could be provided. In contrast, the contract with a low level of service complexity was characterised by a close relationship between service engineers and the customer only for the activities explicitly included in the contract. No additional visits were undertaken and any activities beyond the service agreement were communicated to the customer as recommendations.

Prior studies further suggested that relational capabilities are a governance mechanism to create relational routines (Dyer and Singh, 1998), prevent conflicts and solve problems as well as exchange information (Carey et al., 2011). These insights were confirmed through our case studies as services with high relational capability were characterised by strong relational routines and a high level of information exchange between PSS provider and customer. In addition, we showed that a high evel of relational capability can also be a tool to create competitive advantage as it creates a high level of perceived service quality for the customer through short response times and effective problem solving (Grönroos, 1984; Parasuraman et al., 1988). This was further found to influence the possibility of future sales both of the product and of future service agreements in the context of competitive bidding (Kreye et al., forthcoming).

We showed that the development of relational capabilities was particularly influenced by the level of service complexity as higher complexity leads to higher relational capabilities. However, due to the high level of industrial regulation within the investigated research context of the European healthcare sector, we did not confirm our assumption of higher contractual capabilities for levels of high service complexity. We acknowledge that this is a limitation of the presented research and suggest that future research needs to address this issue in less regulated business contexts.

5.2 Positioning a revised conceptual framework

Based on these findings, we position a revised conceptual framework, depicted in Figure 3. The existence of sector-wide regulations meant that the development of contractual capabilities was not dependent on the level of service complexity, while relational capability increased with the level of service complexity. The investigated cases particularly illustrated that the development of relational capabilities influenced the customer's perceived level of service quality, the customer's attitude towards purchasing new equipment and further services from the provider and the PSS provider's competitive advantage when bidding for new service agreements.

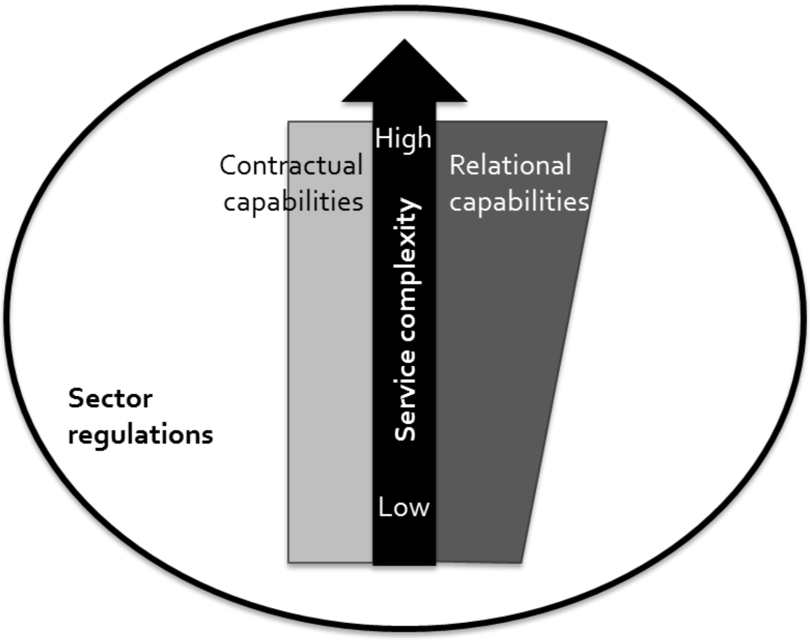

Figure 3. Revised conceptual framework

Our study paves the way for future research which should investigate whether contractual capabilities are of similar importance as relational capabilities in less reguated business environments. As our findings focuses on a highly regulated business sector, we did not find any impact of service complexity on contractual capabilities. Further research should refine our revised conceptual framework by offering further insights into the processes and organisational changes that manufacturers need to address to become successful providers of PSS and add value to their core offerings. In addition, further research also needs to establish whether a company's level of relational (and contractual) capabilities can be used as a tool to judge its readiness to move to the next step along the service ladder in servitization. In other words, a company's capabilities can be used as a basis for the managerial and strategic decision-making process to deliver service offerings of higher levels of complexity.

6. Conclusions and l implications

This paper described the relationaship between service complexity and the development of contractual and relational capabilities within the buyer-supplier relationship for product-service system provision . We presented two industrial cases of one PSS provider and two of their customers, which differed in the level of service complexity. Our empirical study offers two distinct, but inter-related, contributions: (i) service complexity did not impact on contractual capabilities due to the high level regulation within the studied industrial sector; and (ii) increasing levels of service complexity increase the level relational capability development of PSS provider and customer. Developing and mainting relational capabilities can be considered a vital distinguishing feature for PSS relationships. Thus, we contribute to extant literature by extending previous findings to the concept of service complexity and investigating the dyadic PSS relationship. This is important as manufacturing companies tend to increase the level of service complexity of their offerings when shifting to being a provider of PSSs. Our findings suggest that when realising a servitization shift, manufacturing companies need to improve particularly their relational capabilities such as establishing relational routines and behaviour, exchanging knowledge and information and building up inter-personal and inter-organisational trust. While developing contractual capabilities is important, it is the development of relational capabilities that can function as a distinguishing feature in PSS relationships.

The research results have multiple implications for management practice. First, manufacturers in highly regulated industry sectors should focus mainly on the development of relational rather than contractual capabilities as a distinguishing feature. The reason for this is that contractual capabilities are typically covered by the sector regulations as legal punishment for opportunistic behaviour is established across company and national borders. Second, EU regulations to standardise operations and processes within the industrial sector may be a useful tool to icrease the global competitiveness of Europe's manufacturers. A high level of industrial regulations means that manufacturers can focus their efforts on developing relational capabilities that improve perceived service quality by the customer and improve the strategic position of manufacturers in the tendering process for new service contracts. Third, these relational capabilities can be developed step-by-step by the manufacturers as they engage in servitization and undergo the service ladder and increase the servoce complexity of their offering. This means that the relational capability may be auseful tool to judge a company's "readiness" to engage in the next step of servitization.

References:

Achrol, R. V. and Gundlach, G. T. (1999). "Legal and social safeguards against opportunism in exchange." *Journal of Retailing* 75(1): 107-124.

Araujo, L. and Spring, M. (2006). "Services, Products, and the Institutional Structure of

Production." *Industrial Marketing Management* 35(7): 797-805.
Badinelli, R., Barile, S., Ng, I., Polese, F., Saviano, M. and Nauta, P. D. (2012). "Viable service systems and decision making in service management." *Journal of Service Management* 23(4): 498-526.
Baines, T., Lightfoot, H., Peppard, J., Johnson, M., Tiwari, A., Shehab, E. and Swink, M. (2009). "Towards an operations strategy for product-centric servitization." *International Journal of Operations & Production Management* 29(5): 494-519.
Batista, L., Smart, A. and Maull, R. (2008). "The systematic perspective of service processes: Underlying theory, architecture and approach." *Production Planning & Control* 19(5): 535-544.
Benedettini, O. and Neely, A. (2011). "Complexity in services: an interpretative framework". POMS 23rd Annual Conference Chicago, Illinois, USA, 20-23 April.
Benedettini, O. and Neely, A. (2012). "Factors influencing service complexity: the perspective of servitized manufacturers ". EurOMA, Amsterdam, The Netherlands, 1-5 July.
Bijlsma-Frankema, K. and Costa, A. C. (2005). "Understanding the trust-control nexus." *International Sociology* 20(3): 259-282.
Bititci, U. S., Martinez, V., Albores, P. and Mendibil, K. (2003). "Creating and sustaining competitive advantage in collaborative systems: The what and the how." *Production Planning & Control* 14(5): 410-425.
Capaldo, A. (2007). "Network structure and innovation: The leveraging of a dual network as a distinctive relational capability." *Strategic Management Journal* 28(6): 585-608.
Carey, S., Lawson, B. and Krause, D. R. (2011). "Social capital configuration, legal bonds and performance in buyer–supplier relationships." *Journal of Operations Management* 29: 277–288.
Davies, A., Brady, T. and Hobday, M. (2006). "Charting a Path Toward Integrated Solutions." *MIT Sloan Management Review* 47(3): 39-48.
Deakin, S., Lane, C. and Wilkinson, F. (1997). "Contract law, trust relations, and incentives for co-operation: A comparative study". in S. Deakin and J. Michie, *Contracts, Cooperation and Competition*. Oxford University Press, Oxford, UK, 105-139.
Dubois, A. and Gadde, L. E. (2002). "Systematic combining: An abductive approach to case research." *Journal of Business Research* 55(7): 553-560.
Dyer, J. H. and Singh, H. (1998). "The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage." *The Academy of Management Review* 23(4): 660-679.
Gemünden, H. G. and Ritter, T. (1997). "Managing technological networks: the concept of network competence". in H. G. Gemünden, T. Ritter and A. Walter, *Relationships and networks in international markets*. Pergamon/Elsevier, Oxford, UK, 294–304.
Grönroos, C. (1984). "A Service Quality Model and its Marketing Implications." *European Journal of Marketing* 18(4): 36-44.
Helfat, C. M. and Peteraf, M. A. (2003). "The Dynamic Resource-Based View: Capability Lifecycles." *Strategic Management Journal* 24: 997-1010.
House of Commons Defence Committee, U. (2009, 21 July). "Helicopter capability - Defence Committee: Memorandum from the Ministry of Defence." Retrieved 08 May 2012, from http://www.publications.parliament.uk/pa/cm200809/cmselect/cmdfence/434/434we10.htm.
Joskow, P. (1988). "Asset specificity and he structure of vertical relationships: Empirical evidence." *Journal of Law, Economics, and Organization* 4(1): 95-118.
Klein Woolthuis, R. K., Hillebrand, B. and Nooteboom, B. (2005). "Trust, contract and relationship development." *Organization Studies* 26(6): 813-840.
Kreye, M. E., Newnes, L. B. and Goh, Y. M. (forthcoming). Uncertainty in Competitive Bidding – A Framework for Product-Service Systems. Production Planning & Control**:** 1-16.

Lewis, M. W. and Grimes, A. J. (1999). "Metatriangulation: Building Theory from Multiple Paradigms." *The Academy of Management Review* 24(4): 672-690.
Lyons, B. and Mehta, J. (1997). "Contracts, opportunism and trust: Self-interest and social orientation." *Cambridge Journal of Economics* 21(2): 239-257.
Mayer, K. J. and Argyres, N. S. (2004). "Learning to Contract: Evidence from the Personal Computer Industry." *Organization Science* 15(4): 394-410.
Miles, B. M. and Huberman, M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. Sage Publications, Thousand Oaks.
Mont, O. K. (2000). Product service-systems. Lund, Sweden, Lund University.
Neely, A., McFarlane, D. and Visnjic, I. (2011). "Complex Service Systems – Identifying Drivers, Characteristics and Success Factors". 18th European Operations Management Association Conference, Cambridge, UK, July.
Ng, I. C. L., Parry, G., Maull, R. and McFarlane, D. (2011). "Complex engineering service systems: a grand challenge". in I. C. L. Ng, G. Parry, P. Wild, D. McFarlane and P. Tasker, *Complex Engineering Service Systems*. Springer, New York, NY, USA.
Parasuraman, A., Zeithaml, V. A. and Berry, L. (1988). "SERVQUAL: A Multiple Item Scale for Measuring Consumer Perceptions of Service Quality." *Journal of Retailing* 64(1): 12-40.
Roehrich, J. K. and Lewis, M. A. (2010). "Towards a model of governance in complex (product-service) inter-organisational systems." *Construction Management and Economics* 28(11): 1155-1164.
Shostack, G. L. (1987). "Service Positioning Through Structural Change." *Journal of Marketing* 51(1): 34-43.
Sivadas, E. and Dwyer, F. R. (2000). "An examination of organizational factors influencing new product success in internal and alliance-based processes." *Journal of Marketing* 64(1): 31-49.
Smith, L., Ng, I. and Maull, R. (2012). "The three value proposition cycles of equipment-based service." *Production Planning & Control* 23(7): 553-570.
Spring, M. and Araujo, L. (2009). "Service, services and products: rethinking operations strategy." *International Journal of Operations & Production Management* 29(5): 444-467.
Stake, R. E. (1995). *The Art of Case Study Research*. Sage, London, UK.
Strauss, A. L. and Corbin, J. (1990). *Basics of Qualitative research: Grounded Theory Procedures and Techniques*. Sage Publications, Newbury Park, CA, USA.
Teece, D. J., Pisano, G. and Shuen, A. (1997). "Dynamic capabilities and strategic management." *Strategic Management Journal* 18(7): 509-533.
Tien, J. M. (2008). "On integration and adaptation in complex service systems." *Journal of Systems Science and Systems Engineering* 17(4): 385-415.
Tukker, A. (2004). "Eight types of Product-Service System; eight ways to suistainability? Experiences from SUSPRONET." *Business Strategy and the Environment* 13: 246-260.
Williamson, O. E. (1985). *The Economic Institutions of Capitalism*. Free Press, New York, NY, USA.
Yin, R. K. (2009). *Case study research: design and methods*. SAGE Publications, Los Angeles, CA, USA.
Zaheer, A., McEvily, B. and Perrone, V. (1998). "Does Trust Matter? Exploring the Effects of Interorganizational and Interpersonal Trust on Performance." *Organization Science* 9(2): 141-159.
Zollo, M. and Winter, S. (2002). "Deliberate learning and the evolution of dynamic capabilities." *Organisational Science* 13(3): 339-351.
Zollo, M. and Winter, S. G. (2002). "Deliberate Learning and the Evolution of Dynamic Capabilities." *Organization Science* 13(3): 339-351.

Assessing Global HVM competitiveness using a life-cycle income statement approach

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Abstract:

Many organisations, industries and sectors in the west are currently struggling to compete with emerging high value manufacturing (EHVM) global economies. Hence, how firms assess the global competiveness of mature high value manufacturing (MHVM) is an area of study currently receiving considerable attention in research terms. This research paper introduces a life cycle 'income statement' approach and argues that MHVM requires a more objective analysis e.g. through direct comparison of 'income statement' to that of their EHVM global competitors. Furthermore, providing innovative solutions to negate the un-competitiveness elements of the income statement is paramount to ensure a competitive business structure. 'Amongst the leader' income statements may determine whether a particular MHVM company, industry or sector will be successful going forward in a new global economy. This may enable firms to architecturally restructure, accordingly, in order to negate the competitive elements of EHVM. An initial 'income statement' analysis examining restructuring within the automotive industry is presented in this paper. Future work will test the approach through exploration of other sectors e.g. global shipbuilding.

Keywords: HVM, High Value Manufacturing, Global competiveness, Income statement analysis.

1. Introduction:

Mature high value manufacturing (MHVM) has seen decade over decade reductions in manufacturing output while the BRIC nations have seen a progressive increase in their emerging high value manufacturing (EHVM) output (*Mellows-Facer, Maer A, 2012*). There is a common view to why this is happening and it is centred around wage and social conditions of the MHVM economies being the root cause of this migration. Further in-depth analysis illustrates that there may be many other contributing factors. In an attempt to negate the MHVM mature conditions, many MHVM companies and sectors have relocated their manufacturing footprints to emerging economies, yet they are still finding it difficult to compete with their EHVM competitors..

Deming (1986) proposed a continuous improvement quality circle tool in the 1960s referred to as PDCA (Plan-Do-Check-Act). This approach, still in use today, is widely attributed to delivering quality products in the auto industry. It is proposed that a continuous improvement PDCA approach to every line item of a company's income statement versus that of its global competitors is paramount to delivering a competitive EBIT (Earnings before interest and tax).

The income statement takes a holistic view of the revenue of a particular product/project, subtracts the expenses/costs of that product or project to arrive at an earnings before interest and tax (EBIT). This technique is a standard business school approach to constructing any project/business. On the surface this analysis is a simple exercise, however, every line item of the income statement has another multi-dimensional layer of analysis that must be undertaken to ensure that is robust and competitive.
In addition, the following areas (macro affordability function (MAF), competitive value chains, 'Muda' fixed cost analysis) are briefly discussed in the following section in order to inform the income statement approach.

1.1 MAF - Macro Affordability Function.

Many product assumptions and, hence, income statements incorporate two fundamental 'error states'. They assume a higher price than what the market can afford and compound this by assuming higher volumes than what the market can sustain. The root cause for these assumptions is a failure to understand the macro affordability function (MAF) for a specific market. Figure 1 illustrates a theoretical MAF for a particular market sector in a particular geographical location. The MAF (*Deerbank Consulting Limited, 2013.*) is essentially a two dimensional price volume curve for a market or product offering that shows the distribution of sales for a given period over a given price band. The MAF in some markets will be normally distributed, can have a skew plus or minus around the mean or can even be bi-modal. The function changes over time and needs to be extrapolated out over the lifecycle of the product to ensure that the volume changes over the product's lifecycle are understood and incorporated into the lifetime volumes. Once the MAF's have been established one can determine the price band in which to sell your product in. Integrating the MAF function between desired price bands defines the total sales that that market can deliver. Once the total market size for your nominated price band is known, one can then estimate fair market share to validate any volume assumptions.

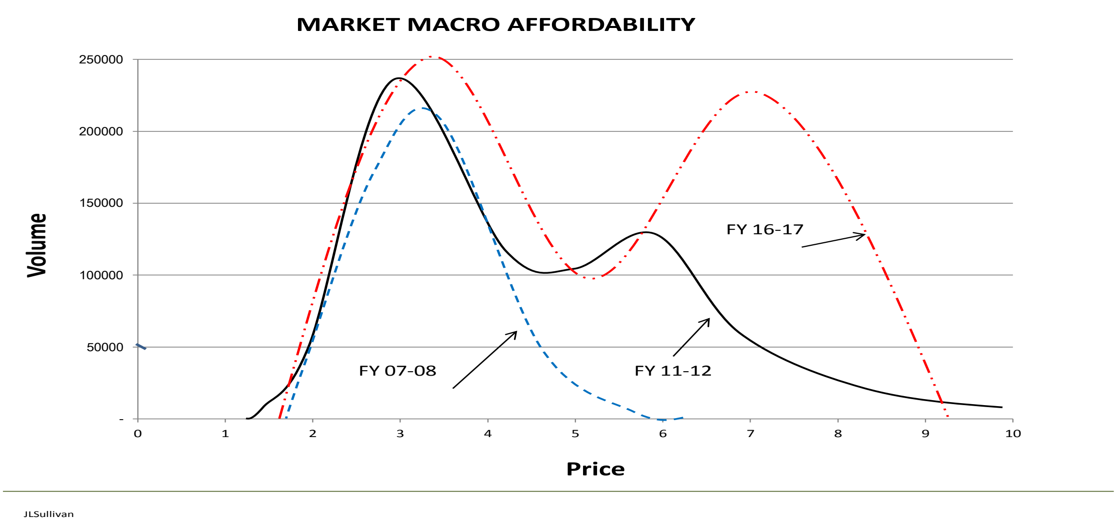

Figure 1 – Macro affordability curves

Unless the product is first to market or has some other unique product positioning strategy, the product positioning needs to be around the ‘sweet spot’ of the MAF. i.e. where 75% of the market volume is. Positioning from a price perspective ensures that provided a product is competitive (which is an assumption in this analysis) the product will command a fair market share even if there is a market shift in price (i.e. a competitor comes in at a lower price. Positioning around the ‘sweet spot’, however, generally means that your revenue deteriorates ultimately putting more pressure on EBIT.

A second consideration is to how best to understand fair market share, to ensure that an income statement reflects the correct amortisation/depreciation per unit values. Fair market share is a difficult metric to establish and it is proposed to take a conservative approach.

1.2 Competitive value chains.

Delivering global competitive material costs in every market is a complex issue faced by every high value manufacturer. There are so many elements in the material cost equation that distort the analysis and, ultimately, the understanding of true competiveness. Economies of scale, freight, duty, taxes, design technologies, MHVM versus EHVM assembly processes, time in transit costs, warehouses (hidden factories), cycle times, etc. all contribute to distorting the true material costs for a given product. A fundamental analysis needs to be undertaken to ensure that a product will be competitive from a material cost point of view in the market a firm wants to compete in. It is imperative that the whole material cost value chain of your product (versus that of competitors) is understood. The value chain needs requires a physical-based analysis in the first instance (i.e. raw commodity costs, man hours, energy units, days in transit, duty rates, cycle times, conversion costs etc.) and then needs to be subsequently converted into currencies. Too often the value chain answer is distorted by point in time currency assumptions, which, at the end of the project are always different. The value chain physicals then needs to be compared with a competitor’s physicals. It becomes very clear from the value chain analysis where the costs for a product are being allocated or spent and whether one will be competitive in that market as a result.

1.3 Muda

Muda (無駄) (*Emiliani, Stec, Grasso, Stodder, 2007*) is a Japanese word meaning "futility; uselessness; idleness; superfluity; waste; wastage; wastefulness", and is a key concept in the Toyota Production System (*Ohno, Taiichi, March 1998).* The traditional approach in the development of an income statement is to include a line item called ‘fixed costs’. Fixed costs are, generally, the cost burden the product carries that is not directly related to production of that product. (i.e. head office overheads, company cars, non-performing assets etc.) and are often considered Muda. It is paramount that a firm understands its competitors Muda as well as their own as it can inform a fixed cost competitive position (which is normally uncompetitive).

2. The consolidated income statement – the harsh reality

Consolidating MAF, value chain material costs, Muda fixed cost analysis, together with the other elements of the income statement results in a more in-depth analysis that may show the competitive reality of a product versus that of a firm's competition. In many cases the reality is that at best, the project is competitive but in many cases may even be negative EBIT despite it being competitive or even 'amongst the leaders' from a product attribute perspective.

What to do about the uncompetitive EBIT position is the 'tough part' for mature MHVM. The 'Invisible hand' (*Smith, 1776.)* argues that unless one has some competitive advantage you end up at best commanding average results. EHVM has that competitive advantage when it comes to EBIT. To overcome this competitive advantage HVM must restructure itself architecturally to regain competitive advantage.

3. A case study – the Auto Industry.

The auto industry is a very good case study of EHVM versus MHVM and what the MHVM auto sector is doing to address the competitive threat of the emerging economies.

Table 1 is an income statement for a typical small sedan, the number one selling auto segment globally by volume. The income statement has been normalised by percentage against showroom price (100%) to enable a comparative analysis to be performed despite the gross revenues being considerably different in the various markets of the world as per the different MAF's described above, refer to figure 1.

In table 1 below, there are four income statements, a baseline EHVM analysis of a vehicle produced and sold in an emerging market (case 1), a baseline MHVM analysis of a vehicle produced in a mature market and sold in a mature market against a historical way of doing business (case 2), an income statement for a vehicle manufactured in a EHVM country but sold in a mature market (case 3), and finally (case 4) where the MHVM has attempted to restructure itself to compete with the EHVM sector in its home mature market. The data in the four cases (i.e. show room prices, typical discounts offered, company annual reports and in some cases the authors experience in the auto industry) has been derived from public domain sources and is an interpretation of what the relevant competitive positions may be. This type of analysis is not untypical of the type of 'forensic' analysis conducted in many companies.

Auto industry income statement analysis EHVM Versus MHVM

	1	2	3	4
Production source	**EHVM**	**MHVM**	**EHVM**	**MHVM**
Market	**EM**	**MM**	**MM**	**MM**
			(Import)	Re-engineered income statement
Gross revenue	**100**	**100**	**100**	**100**
VAT/Sales tax	**(11)**	**(18)**	**(18)**	**(18)**
Dealer margin	**(4)**	**(6)**	**(6)**	**(6)**
FM (Fix marketing)	**(2)**	**(5)**	**(5)**	**(5)**
VM (Var marketing)	**(3)**	**(7)**	**(7)**	**(3)**
Excise duty	**(7)**	-	-	-
Import duty	-	-	**(7)**	-
Shipping	-	-	**(5)**	-
Net revenue	**73**	**65**	**54**	**69**
DMC (Purchase + MIP)	**(57)**	**(43)**	**(39)**	**(43)**
L&OH	**(1)**	**(5)**	**(1)**	**(3)**
Depreciation	**(0.8)**	**(0.7)**	**(0.5)**	**(0.7)**
Fixed costs	**(11)**	**(17)**	**(5)**	**(10)**
Financing	**(0.1)**	**(0.1)**	**(0.1)**	**(0.1)**
Parts profits	**1**	**2**	**2**	**2**
Warranty	**(0.2)**	**(1.4)**	**(1.4)**	**(1.4)**
Transport & logistics	**(0.8)**	**(1.2)**	**(1.2)**	**(1.2)**
Provision	**(2.0)**	**(1.4)**	**(1.4)**	**(1.4)**
EBIT	**1**	**(2)**	**7**	**10**

Source: Deerbank Consulting td.

Table 1 – EHVM versus MHVM income statements for sub 4 m FWD 4 door sedan.

In summary, the income statement analysis highlights a number of fundamental issues:

- Both the EHVM (case 1) and MHVM (case 2) baseline businesses are marginal businesses. The bottom line EBIT is marginally profitable for the EHVM market and marginally negative for the MHVM market, this is counter intuitive to the public at large. (Despite the show room absolute prices in the MHVM markets being in some cases some US$4500 per unit higher than the EHVM market, the EHVM returns a better EBIT).

- The EHVM product sold in the mature market is directionally 8% points higher in EBIT than the local product, (case 3). This incremental EBIT comes about despite having to incur large freight and duty penalties that the local MHVM product does not incur. This is the dilemma that many MHVM industries, sectors and countries are facing, how do you compete against what on the surface appears an impossible competitive disadvantage.

- Case study 4 is a hypothetical case of what the auto industry is trying to do to compete with the EHVM product sold in the mature market. It does appear possible for a MHVM sector to deliver a better EBIT than the EHVM product sold in a mature market. Conceptually, that may appear very obvious (a product that does not incur freight and duty penalties must be more profitable). The obvious extension of this is that MHVM could outperform EHVM in its own emerging market.

4. How has the Auto industry restructured its income statement?

The auto industry for decades has struggled to deliver healthy profits despite billions upon billions of dollars of investment. Accordingly, over the past decade it realised that it needed to architecturally redefine the way it designed, developed, manufactured and procured its vehicles if it was going to survive in the longer term, not only as an industry but also to return reasonable shareholder value add. Accordingly, an analysis of historic practices concluded it needed to design products 50% quicker, produce more output from the same factory (product development through to manufacturing), design products once and then 'plug and play' around the world to deliver genuine global scale and, finally, redefine itself to deliver globally competitive products that would sell around the world. Such restructuring meant that the industry had to completely change the way it had traditionally done business e.g. to migrate to a digital backbone, to change/eliminate traditional job functions and to establish new processes, methods, tools and information standards.

Case (4) in Table 1 illustrates the benefit to the income statement of the auto industry's architectural restructuring over the past decade. There are 3 fundamental elements of the income statement where the auto OEM's restructuring efforts have seen huge benefits namely, BIC products, DFA (Design for assembly) and dramatic reductions in fixed costs. Combining these three elements into a theoretical income statement has the potential to deliver a 'amongst the leaders' EBIT. Taking each element separately:

4.1 BIC products.

The simple fact is that BIC 'best in class' products sell - a good case study here is Hyundai Motor Company (*Hyundai 2012*). Over one product cycle plan period (6 years) they have reduced their variable marketing (VM) approximately by 50%, which equates to a 4% improvement in EBIT by delivering products that are easy to sell. To deliver BIC products needs a passion for understanding the customer, your competition and how to integrate this knowledge into the final product. Very often in any product development program, there is immense pressure to 'back off' on some element of the product to save money, (style, feel, sound, function, feature, appearance etc.) the impact on the competitive positioning on such actions needs to be fully understood to ensure the income statement is not damaged in the process.

4.2 DFA - Design for assembly.

The cost of labour in the MHVM sectors is one of its most competitive disadvantages. Many case studies exist here to show that fully accounted labour costs in EHVM economies can be 20% of those in MHVM economies. (*U.S. Bureau of Labor Statistics 2013.)* To address, but not completely negate this issue, the global auto industry is aggressively tackling DFA - Design for assembly (*Boothroyd, G. 1982*,). Designing products with a 30% reduction in 'time to assemble' from cycle to cycle is not uncommon in the industry. For example, a typical sub 4-metre sedan may have had approximately 30 hours of assembly labour 10 years ago. Today such this product now takes 20 hours to assemble. The effect of this 30% reduction in DFA is approximately a 2% improvement in EBIT for the MHVM analysis.

4.3 Fixed cost reductions.

Fixed costs in MHVM industries, sectors and countries are massively out of step with the EHVM economies (11% EHVM versus 17% MHVM for the auto industry). In many cases this is due to historical legacies such as underutilised physical assets, social norms such as pensions and health care and, in some cases, historical ignorance (i.e. this is the way we have always done it). Whatever the reason the global market is clearly showing MHVM's fixed costs need dramatic reductions to be competitive. The approach the auto industry is taking is to architecturally restructure its business to reduce per unit fixed costs. Their fundamental approach is to adopt global platforms (powertrains, components and go carts) not only within a single company but also across companies. What they are doing is designing 70% of the vehicle to be common across the global network. Having 70% commonality enables their 'industrial machine' to be 'capacitised', based upon global volumes not local volumes, hence, reducing dramatically the per unit fixed costs. Doubling the volume for 70% of the vehicle results in a dramatic reduction in fixed costs per unit. (i.e. 7% EBIT improvement in the income statement). Whilst this is much easier to do for some commodities than others, over a 10-year period, a disciplined approach to fixed costs reductions throughout the vehicle value chain (suppliers through to OEM assembly plants) has the potential to deliver competitive fixed costs per unit as a percentage of revenue as compared with the EHVM sector.

Combining the three above elements, BIC products, DFA and fixed cost reductions into the income statement, case 4, shows that it is architecturally possible to transform your business/industry from a marginally profitable business to one that has a strong EBIT and be competitive with the EHVM competitors.

5. HVM UK competitiveness study – Global ship building

The auto industry as a result of global competitive pressure has shown that it is possible to restructure its industry to take on the EHVM competitors and potentially return a competitive or better EBIT than the emerging market competitors. The question is, 'is it possible for other industries/sectors' to architecturally restructure in the UK and be globally competitive? Future work will look to examine the global ship building industry in detail with the aim to develop in depth baseline data to assist with development of an industrial sector strategy for ship-building at a national level within the UK.

To support this analysis, it is proposed to undertake sector market analysis, sector income statement development, current state PD process analysis, and current state manufacturing process analysis.

5.1 Sector market analysis

This analysis will take a +/-25-year look at the global large ship building industry. The aim is to understand and quantify the global market trends over the past 25 years, understand the global 'mega' trends and forecast where the industry is expected to migrate to over the next 25 years. The analysis should include but not be restricted to number of ships built, market sector trends, global manufacturing 'foot print analysis', customers industrial, military, government strategies and support mechanisms, T1/T2/T3 players and technologies deployed.

5.2 Sector 'income statement' analysis

As presented in this paper, the 'income statement' analysis will look to determine whether the sector when assessed at an income statement level is profitable or not. This analysis should include development of generic income statements for a number of large ship projects around the world. It is expected that there would be an income statement for a 'third world' manufacturing site, a military project in the UK and a BIC mature manufacturing footprint. The income statement would include revenue, design material costs, fixed costs, tooling and facility costs, depreciation and amortisation, engineering and development costs etc. It is proposed that most of the data will be derived from public domain sourced information, visits to industrial sites and quantification of the physicals involved.

5.3 Current state PD processes.

This analysis will look to understand the ship-building 'PD (product development) processes at a macro scale. The analysis would include its timescales, the resources required, the analytical tool set deployed, the test and development phases and requirements, the degree of bespoke-ness, integration processes, critical path elements, the footprint of the global development centres, data structures deployed etc.

It is proposed that a comparative study will also look at the automotive and aero industries.

5.4 Current state Manufacturing process.

This analysis will look at mapping the manufacturing process in building large ships. It is proposed that the analysis should be undertaken on three sites, a third world site, a modern state of the art mature site and a military site. The analysis should include but not be restricted time lines, assets deployed (physical and human), technologies deployed, amount of bespoke-ness versus off site manufacture, supply lines, degree of leanness, comparison versus the auto and aero industries, on time completion histories, error state analysis.

6. Conclusions

Many organisations, industries and sectors in the west are currently struggling to compete with emerging high value manufacturing (EHVM) global economies. Hence, how firms assess the global competiveness of mature high value manufacturing (MHVM) is an area of study currently receiving considerable attention in research terms.

This research paper introduces a life cycle 'income statement' approach and argues that MHVM requires a more objective analysis e.g. through direct comparison of 'income statement' to that of their EHVM global competitors. Furthermore, providing innovative solutions to negate the un-competitiveness elements of the income statement is paramount to ensure a competitive business structure. 'Amongst the leader' income statements may determine whether a particular MHVM company, industry or sector will be successful going forward in a new global economy.

This may enable firms to architecturally restructure, accordingly, in order to negate the competitive elements of EHVM. An initial 'income statement' analysis examining restructuring within the automotive industry is presented in this paper.

Future work will test the approach through exploration of other sectors e.g. global ship-building.

References:

(1) Boothroyd, G. (1982), *"Design for assembly: The Road to Higher productivity",* Assembly Engineering.

(2) Deerbank Consulting Limited (2013). *The Macro Affordability Function* – an internal company process for analysing price volume sensitivity for a particular market in a particular country.

(3) Deming, W. Edwards (1986). *Out of the crisis.* MIT centre for Advanced Engineering Study, ISBN 0-911379-01-0

(4) Emiliani, Bob; Stec, David; Grasso, Lawrence; Stodder, James (2007). *Better thinking, better results: case study and analysis of an enterprise-wide lean transformation* (2nd ed.). Kensington, Conn: Center for Lean Business Management. ISBN 978-0-9722591-2-5.

(5) Hyundai Motor Company (2012). *Investor presentation*, page 5

(6) Mellows-Facer, Maer A, (2012). *International comparisons of manufacturing output.* UK House of Commons Library, Standard note SN/EP/5809

(7) Ohno, Taiichi (March 1998), *Toyota Production System: Beyond Large-Scale Production*, Productivity Press, ISBN 978-0-915299-14-0

(8) Roos, Daniel, Ph.D.; Womack, James P., Ph.D.; Jones, Daniel T.: *The Machine That Changed the World : The Story of Lean Production*, Harper Perennial (November 1991), ISBN 0060974176, ISBN 978-0060974176.

(9) Smith, A (1776). *Wealth of Nations*, Book 1, chapter 7. (New Ideas from dead economists – An introduction to modern economic thought. Buchholz, Todd G. ISBN 978-0-452-28844-7, 1985)

(10) U.S. Bureau of Labor Statistics (2013). *International comparisons of hourly compensation costs in manufacturing 1996-2012.* BLS.gov

Virtual Experiment Fields for Logistical Problem Solving

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Abstract

Globalization has had an important impact on how to structure and manage logistical networks over the last decades. Logistical planning cases are influenced by a higher complexity as well as a need for reliable solutions and real-time decision support. A Virtual Experiment Field (VEF) is an effective tool for supporting the simulative evaluation of logistics problems within supply chains or other complex logistics process environments. Reusable modules and optimization methods are key elements of VEF and offer means to create implementation recommendations for real-time decisions in new as well as known problems.

The procedure is based on a combined approach, integrating an analysis of recurring elements within simulation studies with interdisciplinary methods. The referred methods are aggregated from the fields of design of experiments, computer simulation as well as logistics process planning. The approach is verified by two case studies where the procedure was applied to the automotive industry.

The results can be divided into three parts. First, the paper presents a detailed definition of the modules that compose a Virtual Experiment Field: a specific logistical planning problem, logistics planning measures, a simulation model, an experiment plan and interpretation rules. All components are described by their content and the specific format required by the type of planning problem. Second, a procedure to develop a fully operational VEF is presented. It shows a step-by-step approach to derive the required elements from real-life planning tasks. Third, the step-by-step approach is enriched with methods from various research disciplines that facilitate the definition and successful use of a VEF. This includes e.g. a method to develop powerful measures to accomplish a specific planning task.

The theoretical findings were successfully applied to two very different use cases: The first use case is placed in the field of operating an international supply network with various suppliers and customers while the second focuses on the strategic network design in outbound distribution.

The use cases show that VEF are effective tools for the construction of real-time decision support systems. VEF offer a promising path for fast and reliable realization of planning tasks by using the power of simulation models. Further research is needed to incorporate additional methods, e.g. for experimental design and iterated simulation search algorithms.

Key Words: Virtual Experiment Fields, Logistics Planning, Supply Chain Management, Simulation, Design of Experiments

1. Purpose of Virtual Experiment Fields

The automotive industry has gone through dramatic changes due to the consequences of globalization. International competition has led to an increase of model variety as well as shorter model lifecycles (Mößmer et al., 2007). Globalization affects planning problems from product development to production, logistics and sales. In logistics, financial pressure has led to global sourcing and distribution, increasing the international dependencies of actors within the supply chain. After continuously optimizing and synchronizing the supply chain, stock levels have been lowered significantly. Thus, even small local incidents (e.g. a traffic jam) may cause turbulences in the downstream supply chain processes because deviations cannot be covered by inventory stocks. These effects show the necessity of shorter cycles in logistics planning and modeling of more complex logistics systems. Only through the improvement of information technology it is now possible to address these complex planning tasks with logistical assistance systems (LAS) and Decision Support Systems (DSS). Meanwhile it still results in a high level of effort to conduct a complex simulation study because simulation experiments have to be carefully planned, carried out and interpreted. A new planning environment to improve this issue is therefore necessary

Virtual Experiment Fields (VEF) have been described as a new model for increasing decision speed and quality within logistics planning and design by (Toth & Liebler, 2012). The approach offers methods and tools for an automated generation and evaluation of decision alternatives. Toth & Liebler show that the combination of high-experience planners' knowledge and powerful simulation tools can boost decision quality while maintaining low decision lead times of less than 30 minutes. VEF are a new planning methodology to improve decision speed and accuracy in complex logistics planning situations. It combines powerful simulation modeling software with a structured derivation of applicable measures and a (semi-) automatic experiment planning and execution. Based on the VEF method, software tools can be built or simulation projects can be conducted to make the benefit accessible to logistics planners.

VEF are designed to bridge the gap between a planning problem and the best action to take. Figure 1 shows the three basic phases of a VEF. Initial phase is the enabling or design of the VEF, which comprises of defining relevant processes, planning of measures and enabling a software tool during the design of supply chains. During the 2nd phase of surveillance, automated algorithms allow for a permanent tracking of the dynamic supply chain situation including forecasting critical factor combinations. Exceptional situations are identified during the permanent surveillance phase. Decision taking is then supported by the structured and automated generation and evaluation of alternatives. An experiment plan condenses known best-case alternatives and independently evaluates further improvement potential by automatically adapting itself to situational factors such as the supply chain situation, the problem complexity or decision lead time. The findings of those experiments as well as new supply chain configurations can then be added as the enabling phase is conducted sequentially to increase the VEF's performance and scope.

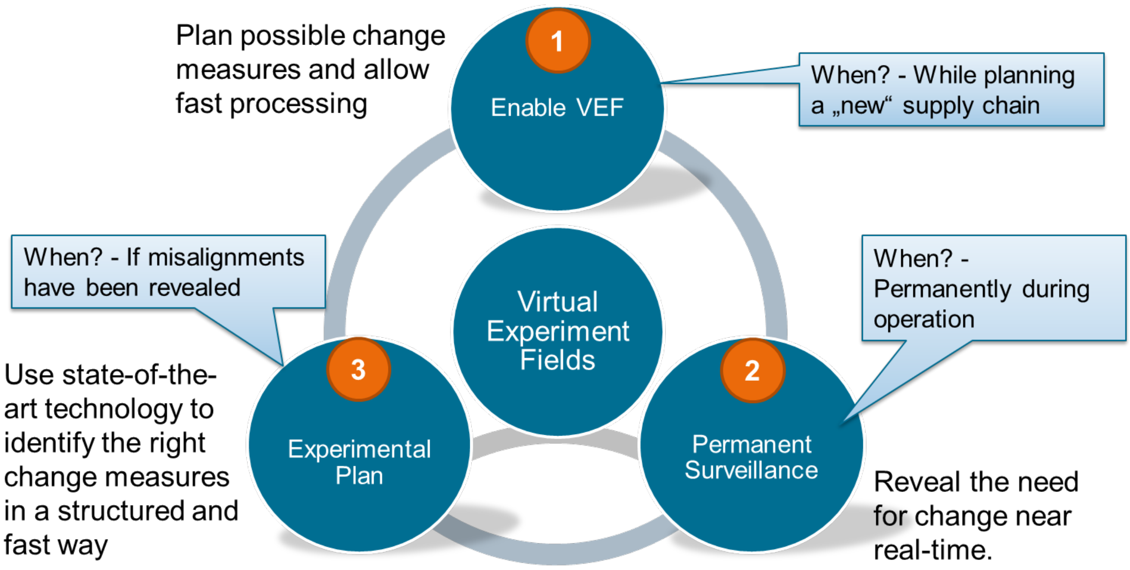


Figure 1: VEF Phases

The paper focuses on the design of Virtual Experiment Fields. It offers a detailed description of all elements needed for enabling a VEF and proposes a procedure for implementation. In Chapter 2, the elements of VEF are defined. Hereafter, the chapter Designing Virtual Experiment Field explains the process of implementing each of these elements. The paper closes with two examples from the German automotive industry in which the VEF approach has been proven.

2. Elements of Virtual Experiment Fields in Logistics Planning

The concept of VEF is based on research in the fields of classic simulation, experimental design and computational simulation. VEF are an effective tool in supporting the simulative evaluation of logistics problems within complex supply chains or other complex logistics process environment. Via the definition of re-usable elements and optimization methods, VEF offer means to take real-time decisions for new as well as known problems. It is their main purpose to support logistics specialists in identifying non-optimal situations, finding reliable solutions in dynamically influenced systems and to do so in a real-time manner (Toth & Liebler, 2012). First of all, the necessary elements for implementing VEF have to be described in the following.

VEF extend the classic simulation approaches by integrating simulation-based logistics planning methods with standardized experiments in order to evaluate logistical options. Five basic elements of VEF have been identified: a *simulation model*, an *experiment plan*, one or more *logistics planning problems*, one or more *logistics planning measures* and *interpretation rules* for interpreting the simulation results. Both experiment planning as well as result interpretation can be either automated as well as semi-automated to support simulation projects. Decreasing planning cycle times then offer the possibility to continuously evaluate the options within the scope of the VEF also enabling the usage of close to real-time data.

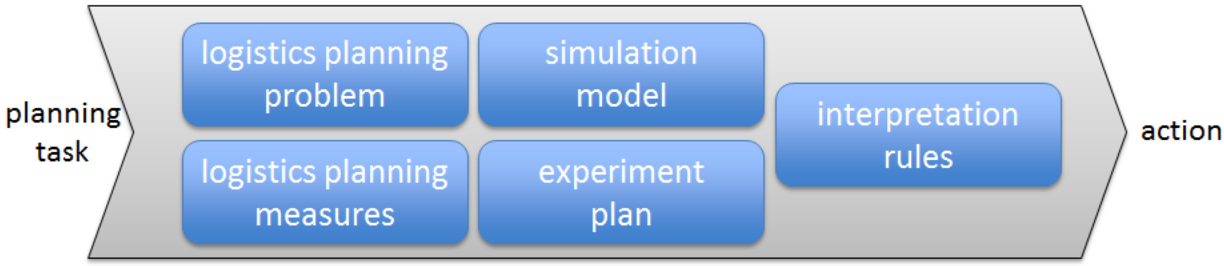


Figure 2: Basic Elements of Virtual Experiment Fields in Logistics Planning

Logistics planning problems are elementary for the definition of the scope of a VEF. They occur in all levels of logistics planning: Supply Chain Design, Supply Chain Planning and Supply Chain Operations (Hellingrath & ten Hompel, 2007; Beller, 2010) A planning task can consist of several planning problems. A planning problem is a dedicated task that an acting person or organization within a process structure has to solve. The most important information that has to be identified for a logistics planning problem is the *goal* ("What does the planner want to achieve?") and the *scope* ("What is the environment in which the goal needs to be achieved?") of the planning problem. Goals are forced by the planning problem itself or by the company. (Fleischmann, 2007) suggests a planning matrix that categorizes logistics planning problems based on the corresponding process in the value chain and the timely scope of the planning.

For instance, in an operational environment, the material planner of a receiving company in an international supply chain has the task to optimize orders for a certain material based on transport costs within his field of responsibility. In this example, the minimization of transport costs and environmental pollution while ensuring supply availability defines the goals. The scope of this logistics planning problem covers all operational activities that are performed in a Supply Chain to deliver the particular material to the customer.

A VEF usually contains more than one planning problem as they are part of the same supply chain thus based on the (at least partly) same process structure. This ensures the reusability of simulation models and solution strategies. In the above example, if the material planner was asked for the carbon footprint of the supply chain, this problem would be very similar as most relevant processes would be the same as for the first planning problem to optimize material. Both logistics planning problems can be part of the very same Virtual Experiment Field. In this way, the sum of all planning problems set the boundaries for a VEF as all relevant business processes and goals need to be considered in order to optimally support the decision making process.

Planning problems can be solved by the application of one or more planning measures that are described in the following paragraph.

A **logistics planning measure** represents the degree of freedom of a particular planner that he uses in the fulfillment of his task. In a VEF, a logistics planning measure is defined by a certain action that a planner is capable and allowed to do, or - speaking in a modeling language - a variable (or set thereof) that the planner modifies within a given change range. Those actions are limited, well-known and their impact is measureable. As with logistics planning problems, a VEF contains numerous logistics planning measures that represent possible actions by all actors that are within the VEF's scope and that are relevant for the goals of the VEF.

In the above mentioned example, the planner could have the possibilities to change transport modes or order quantities and dates. In case of a planning problem concerning predicted shortages, the planner could chose to change the mode of transport from ship transport to air freight. This would have a positive impact on the goals of short lead times and a negative impact on the goal of minimizing the carbon footprint and transport costs.

Logistics planning tasks and logistics planning measures completely describe all actors, processes and the nature of all variables. The results form a parameterized version of the planners' options and are input for the model that evaluates the application of derived modification possibilities. For the given task of scenario-based evaluation of logistic planning problems and measures simulation is the most suitable method. The process of transferring feasible measures into a simulation model in order to limit the simulation to reasonable experiments is described in chapter 3.

The **computer simulation model** is the virtual representation of a real-life structure (Stachowiak, 1973). The purpose of a logistics simulation model for the planner is to pre-examine potential real life actions quickly and with minimal costs in order to evaluate the effects on the planning goals. Both speed and cost factors are a main difference for the need of re-usable VEF in comparison with classical simulation approaches. Findings from within the model environment can then be used for decision-taking in real life. The process of computer simulation modeling has been described extendedly in classic and modern logistics research (i.e. Kuhn & Rabe, 1998; Law & Kelton, 2007; Santner, 2003 and others).

The simulation model is one of the two core components in the decision making process as the quality of the model predefines the quality of the decisions derived from the model. Due to the high amount of resources that are spent on the modeling process, VEF simulation models are designed to be reusable. Automatic or semiautomatic updates of the model according to real-time changes of e.g. the workload within the analyzed system lead to a massive improvement on the necessary time for evaluation. The multiple-use-approach of VEF is shown through

- reusable simulation models of VEF within operational decision making systems
- numerous logistics planning problems incorporated in one VEF simulation model (see above)
- numerous logistics planning measures incorporated in one VEF simulation model (see above)

The second core component is the set of input values for the scenarios to be calculated. These are condensed in the experiment plan.

The **experiment plan** summarizes all computer experiments that are to be conducted with the simulation model in order to solve the logistics planning problem. It describes the parameter setting for each experiment and contains a list of all experiments to be conducted (VDI, 1997). Each scenario in an experiment plan represents a possible measure to be taken.

Experiment plans can differ widely depending on the possible measures to be applied for a specific planning problem. The amount of alterations for a measure, as well as the variety of combinations of measures, leads to a potentially high number of experiments, and thus results in a large experiment plan. Effective experiment planning can only be achieved by considering the specific characteristics of the simulation model such as the number of factors and factor steps.

Continuing the introduced example, the planner has a variety of possible order quantity ranges and a range of possible ordering moments. For the latter, a daily based alteration could be sufficient, for the ordering quantity only specific amounts (e.g. 100, 200, and 300) might be reasonable. The experiment plan can now be derived and fully described.

Identifying these characteristics for logistics simulation models and applying the right experimental strategies accordingly is a key success factor in using VEF.

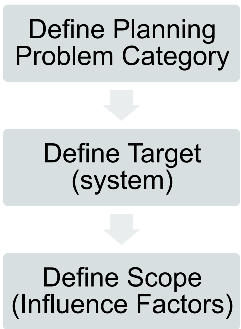
Interpretation Rules summarize a set of rules for interpretation of the simulation results or to transfer the findings back to real life processes. Interpretation rules can fall into one of the three categories rules for analyzing one scenario, comparing scenarios or heuristics for iterative approaches. It is obvious that the interpretation rules have to collude with the planning goals as defined in the specific planning problem.

In our example a rule could be an upper bound for the increase upon the ecological footprint. Scenarios with results above this upper bound would cause a new iteration with a forced decrease in the usage of transport modes with high pollution effects.

3. Designing Virtual Experiment Fields

In the following, the process of designing a Virtual Experiment Field is described. Hereafter it is approved by two use cases.

Modeling Logistics Planning Problems



Describing one or more specific logistics planning problems is the first step in the building process of a VEF. A planning problem is fully specified when its category, its planning goal (target system) and the Scope of the logistics system to be considered (influencing factors) have been defined.

During the first step, the category of the planning problem is determined. The categories are introduced in the following paragraph. The field of logistics covers a wide array of planning problems. As both the planning process as well as the experimental design strategies depend on the characteristics of the specific planning problem, VEF do not apply a “one-fits-all” approach. Instead, a flexible approach based on a categorization of planning approaches is used. Thus, the following planning problems are introduced:

Quasi-optimization problems aim at optimizing one or more target dimensions within a logistics system. During the simulation based optimization, input data is varied multiple times (based on variation rules) in order to find the set of input parameters that leads to the best target dimension(s). This approach implies the ability to put the simulation results in a cardinal order even if multiple targets are defined.

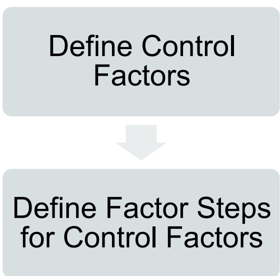
During a *scenario comparison*, planning measures have been derived through empirical or scientific means to evaluate their effect upon a number of target dimensions. As no ex ante definition of overall optimization criteria have to be considered, a deep analysis of the simulation results is possible. During numerous iterations, target conflicts are analyzed and hypotheses are inductively derived and dis/proved on the simulated logistics system.

Risk evaluation and prevention problems focus on the probability of a deviation of the target dimensions caused by external and internal effects (Schneider, 2009). Input data is systematically varied in order to determine the probabilities and the circumstances of deviations. This information is then used to alter the structure of the logistics system in order to decrease the probability and the possible impact of unintended changes in the target dimensions.

The subsequent activity is the definition of a target system. A *target system* includes one or more targets that represent the goal of the planning problem i.e. minimized cost or minimized usage of capacity. Depending on the category of logistics planning problem, each target system can be reduced to one cardinally scaled value or not. E.g. for a logistics planning problem that aims to optimize an operational decision, it is necessary to define a target that is cardinally scaled to determine a hierarchy of the quality of the measures. An automated optimization is only possible if a comparison and ranking of the simulation results can be conducted. During a strategic scenario comparison however, one has to allow the assessment of multiple target values, where it might not be possible to ex ante determine the weight of each target value for final decision. The definition of the target system therefore depends on the previously defined categorization of the logistics planning problem. Generic target systems that serve as input for VEF can be found in literature (Wiendahl, Petermann & Glässner, 1992; Keller & Hellingrath, 2007).

Defining *influencing factors, processes and control* rules that determine the relationship between structure and processes is the final step in the description of logistics planning problems. They are derived from the scope of the logistics system that is to be analyzed. Based on standard modeling approaches as described by Klingebiel (2009, p. 60) and VDI (2010), real processes are transferred to virtual models. Each specific logistics planning problem is to be analyzed concerning which processes need to be considered and to which detail. All quantities that have an effect on a specific planning problem (more precisely on its target) can be summarized as influencing factors and need to be determined when initially describing the logistics planning problem. During this phase, it is usually enough to complete a logical description of the real processes as the IT implementation will be done in the later phase of simulation modeling. The same applies to the description of logistics planning measures.

Modeling Logistics Planning Measures



As the performance of a logistics system is the outcome of a set of individual activities, VEF's contain a description of each activity as a logistics planning measure. A logistics planning measure represents the intentional and purposeful alteration of processes and resources by an actor within a supply chain, each planner has to decide *what* (define control factors) to change and *how* (define reasonable range and factor steps within this range) to change it. Reflecting these decisions, modeling logistics planning measures comprises of the steps "define control factors" and "define factor steps for control factors".

It is important to understand that each logistics planning measure is up front independent of one particular planning problem, as a logistics planning measure can be useful in the solution of multiple planning problems (or only one or even none). In order to show the dependencies of logistics tasks and measures, a matrix is introduced later in this article (see below "Finding Optimal Solutions").

Error! Reference source not found. shows the influencing factors of the model description within a VEF. Influencing factors comprise *control factors, ambient factors* and *system load* (based on Kleppmann, 2011). The system load is a special set of influence factors that has the ability to behave either as a control or as an ambient factor. In a VEF, the influencing factors that can be directly influenced by a certain logistics planning measure are considered *control factors, whereas all factors that are not directly influenced are considered ambient factors*. The identification of control factors is the first step in defining logistics planning measures. Each measure therefore contains at least one control factor. The first step of modeling a logistics planning measure is to separate between control factors and ambient factors. What is considered a control factor in a certain measure may well be an ambient factor for another measure.

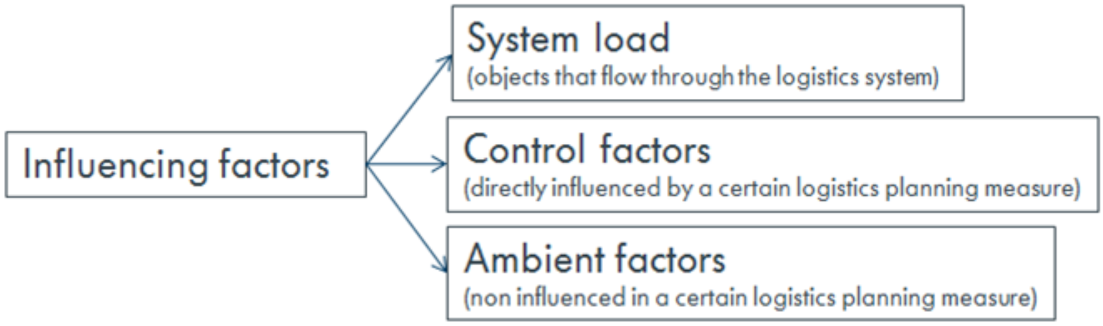
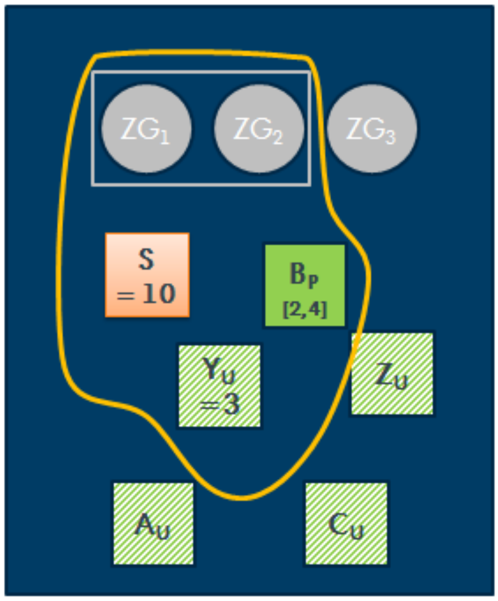


Figure 3: Influencing factors within the VEF model

The system load has to be considered as a specific influencing factor. It describes the desired transformation performance of a logistics system (Reeker & Wagenitz, 2011) and is usually of dynamic character, thus its influence on logistics planning tasks is crucial. Depending on the specific logistics planning measure, the system load is either considered an ambient factor (e.g. in the evaluation of operational decisions) or a control factor (e.g. in a strategic analysis).

After the definition of control and ambient factors, the factors steps have to be decided for the control factors. Based on their real world representation, they will most likely have some restrictions such as weekly shipping schedules, lower and upper capacity boundaries or lot sizes. Along with the control factor definition, the possible ranges for each control factor are determined. If the influencing factors can best be described as a probability distribution, statistical methods are applied (Law & Kelton, 2007, p. 275ff). Often initial quantifications of control factors are based on expert estimations and altered over time by evolutionary approaches or an increased knowledge about the logistics process. In some cases, hypothetical settings are also possible, e.g. in a strategic scenario comparison.

Error! Reference source not found. shows all logical elements that have been defined in the previous steps. The figure illustrates a very simple example of a Virtual Experiment Field with its elements in order to simplify the understanding of proposed taxonomy.



- The blue box represents the Virtual Experiment Field.
- The yellow boundary shows the Scope of one dedicated planning problem within the VEF, while Z_U, A_U and C_U are ambient factors that are not relevant for the simulation of the certain planning problem (but for other planning problems within the same VEF).
- ZG_1 and ZG_2 form a target system with two targets
- The Control Factor B_P describes a measure to be evaluated. Its value can be set within an range of [2,4]
- The system load S is determined to be 10.

- The ambient factor Y_U is determined to be 3.

Figure 1: Representation of Parameters within a VEF

Other Scenarios within the same VEF might incorporate other elements such as ZG_3 and C_U.

Bringing together planning problems and measures - The Simulation Model

Implement Simulation Model

The modeling of logistics systems has been researched extensively in modern literature. Klingebiel (2009) e.g. describes a six phase approach for modeling:

1. Identification of the application domain
2. Definition of scope
3. Determination of model framework incl. formal description language
4. Modeling
5. Using the model
6. Action based on model findings

Independent of the specific modeling approach, the pre-definition of logistics planning problems and measures concludes in a great amount of data that is necessary for modeling. In Klingebiel's approach, Phases 1 and 2 have been covered during the definition of logistics planning problems and measures. This leaves phases 3 and 4 for the conclusion of the modeling process.

In order to derive the simulation model the following components are necessary:

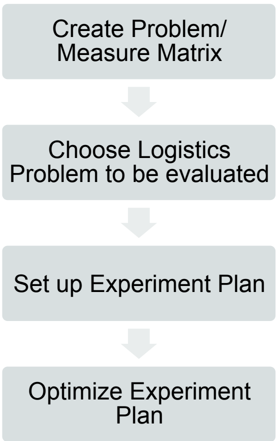
1. Structure model and processes (material and information flow, planning processes) that form the bases of a simulation model and are mostly non-flexible. Objects such as construction sites, distribution centers, truck and flight connections and transport schedules are part of the structure model. The structure can be derived from the scope of all planning problems in the VEF.
2. Material flow data substantiating the system load as well as ambient factor data. This data has to be up-to-date as well as updated in appropriate time periods. Examples for this kind of data can be production schedules, customer demand and stock levels.
3. Logistics planning measures that where pre-defined and formalized as parameter sets of control factors have to be integrated in the model in order to enable an on demand application.

Figure 2 describes how each parameter is derived from the predefined VEF elements. In order to maximize the quality of the findings of the VEF, model validation is a necessary activity during modeling. (Rabe, 2007). Typically, a set of real life data is identified, that contains both input and target dimensions of a simulation model. Validation is considered successful, if the simulation shows the same results as the real-life target data. It is encouraged to use the VEF approach for model validation, as model validation scenarios can be described in reusable experiment plans.

In order to implement these components a suitable simulation tool is necessary. It has to be capable of mapping multi-stage distribution processes with their basic elements as well as production and ordering schedules including product structure and finally a broad variety of performance indicators. In (Seidel and Klingebiel, 2005) thirteen tools within the logistics segment have been analyzed according to their fit for holistic mapping of object oriented structures as it is the case for VEF.

OTD-NET was identified as the most suitable tool for simulations with the mentioned requirements profile. It is described in (Wagenitz, 2007) and consists of the following components: *Graphical Modeling Environment* where all objects and processes can be modeled that then form the *database*, as well as a C++ based Simulator that conducts the experiments and writes the results back into the database and finally the OTD-Analyzer that enables the user to analyze individual performance indicators.

Finding optimal solutions – Design of Experiments



The design of simulation experiments is a key element of the VEF approach as it is crucial for both planning quality as well as planning lead times (Kleppmann, 2011). The VEF contains a 4-step approach to designing an experiment plan which is built around a problem/measure-matrix and an experiment plan. The steps are visualized in the figure on the left hand side.

The heart of the VEF is a *matrix merging planning problems and measures* by identifying the effect of each measure upon each problem (cp. Table 1). This step serves to choose measure with an appropriate effect on the current planning problem. Therefore it needs to be determined which measure has a potential effect on which logistics planning problem. As the determination of an influence can be difficult to prove, multiple methods can be applied to represent dependencies:

- Mathematical procedures: Analytical as well as factor-by-factor simulation studies can (dis-)prove an effect.
- Process analysis methods that are based on a step-by-step tendency analysis can be used to (dis-)prove an effect.
- Empiric analysis such as observation can be used in particularly complex situations. However they need to be validated thoroughly as ambient effects can influence their validity.

	Measure 1	**Measure 2**	**Measure 3**
Planning Problem 1	Positive	Unknown	Negative
Planning Problem 2	Negative	Positive	Positive
Planning Problem 3	No Effect	Negative	Positive

Table 1: Problem/ Measure Matrix

The matrix reduces the complexity of logistics model based simulation for logistics decision making as the scope of both the model as well as the experiment plan can be quickly determined. *By choosing a planning problem* in a VEF all relevant measures are determined via the matrix and all variables within the VEF can be identified. Decision-Support-Systems (DSS) can benefit widely from using the VEF approach. By using the VEF methodology including the problem/measure matrix, measures can be quickly and automatically identified, then modeled and evaluated in the structure model. In this case, only a subset of the full VEF is taken into consideration for the specific scenario which reduces experiment plan complexity, model sizes and runtimes. Results are then worked up and presented to the end user by the output layer of the DSS. The matrix approach can also be used by project groups to contain knowledge on recurring simulation scenarios, as known planning problems and measures are contained in the VEF for later reuse and extension.

A very simple version of the experiment plan is used during the permanent surveillance phase (see Figure 1). During this phase, the logistics system is fed with online data to continually update evaluate deviations of the intended goals. Only when this deviation is identified, measures are defined and evaluated. Thus, the experiment during the surveillance phase is based on real life data only.

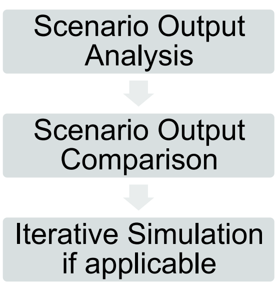
In phase 3 (see Figure 1) the *initial set up of a full factorial experiment plan* is performed based on the scenario decision. While all factor steps of control variables have been specified during measure definition, ambient variables can only be defined during the setup of the experiment plan. This is due to the fact that only when all control variables among the relevant influence values have been chosen, the remaining can be considered ambient values. For control factors, each possible factor step or factors step combination (in the case of multiple control factors within one measure) represents a scenario to be evaluated. Based on the predefined ranges, factors steps are determined. If continuous intervals are possible for certain measures, it has to be chosen which factors steps are considered. Ambient factor value specification is usually performed deductively based on real world observation. Once this step is finished, a full factorial experiment plan of the chosen scenario simulation is available.

However, logistics systems incorporate highly complex processes. The full factorial experiment designs for logistics often lead to inefficiently big experiment plans that need a high amount of resources to be realized. Thus efficient experiment plans are a challenge. Intelligent derivation of experiments can already lead to a rigorous decrease in the amount of scenarios. Yet, during the Phase of *optimization of the experiment plan* it is the intention to increase the efficiency of the simulation. This is necessary due to the nature of logistics systems:

- Logistic simulation models mostly have a *high number of factors* leading to an even higher number of potential correlations. Thus the application of full factorial experiment designs is not possible in most cases.
- Logistic simulation models often have *discontinuous response surfaces* (e.g. for system load, capacity or production programs), which aggravates the application of search strategies based on simple quality criteria.
- Logistics Systems are *highly dynamic* while most Design of Experiment methodology was developed with static factors in mind.

Based on the criteria of the logistics simulation model, three strategies are available for increasing the efficiency of logistics simulation experiments: Focusing on only significant factor step combinations ("Screening" incl. Placket-Burmann designs (Kleppmann, 2011), Optimizing the search field (use of the "Response Surface Method" (Box & Wilson, 1951) and the use of exploratory search metaheuristics (Weicker, 2007). Further research for the criteria-based application of the strategies is needed and currently undertaken.

Interpreting the Scenario Simulation Outcome



After a successful simulation great amounts of output data need to be analyzed. Based on the category of a logistics planning problem and on the output data, further steps can be decided, such as a tweaking of the factors and a rerun of the VEF process.

The analysis of output data is highly dependent on the kind of target system to be used. As it needs to be individually planned for a certain simulation study and planning problem category, this paper can only give limited insight into possible methods for Interpreting Simulation Output Data. The basic analysis of simulation output data falls into one of the three categories

- Analysis of all simulation runs in one scenario
- Comparing scenarios between each other
- Conducting iterative reruns of the experiment in order to improve result data

During the *"Scenario Output Analysis"* only one scenario is analyzed. In order to evaluate one scenario, usually multiple simulation runs are necessary to ensure statistically correct figures, thus evaluating the "true characteristics" (Law & Kelton, 2007, p. 485) of a simulation model. The decision of re-running a scenario with stochastic input values should be done based on a confidence estimation that is 90% or higher. As long as the target values do not reach this level of confidence, additional simulation runs of this scenario are necessary.

As logistics systems are dynamic, time plots of certain target values are used as well to show the behavior of a logistics system over time and control boundary exceptions. In this case each individual simulation run has to be scanned for boundary exceptions and the target value describes the probability of a boundary exception for each simulation run. An example for this kind of target system is the underscoring of security levels in warehouse stock.

For the *"Scenario Output Comparison"* sophisticated statistical methods such as modified confidence intervals are available (Law & Kelton, 2007, p. 548). Also the ranking of multiple Scenarios falls into this category as it will occur in most optimization planning problems.

During the third phase of the interpretation, it is determined if and how rule-based changes to the influencing factors are done to form new scenarios to be evaluated. For optimization planning problems, iterative methods such as Tabu Search and Evolutionary Algorithms (Weicker, 2007) offer methods to improve the optimization result. This is achieved by choosing those scenarios that offer best results and altering some or all of the influencing values before re-evaluating the new scenario. These methods suit very well for improving the result quality in automated decision support systems.

4. Use Case 1: Decision Support in Supply Chain Operation based on Virtual Experiment Fields

The first use case to demonstrate the functionality of VEF is placed in the field of the operational management of an international supply network in the automotive industry.

The international supply network is characterized by two sites that fabricate the same product in two remote regions of the world, e.g. in Germany and South Africa. The suppliers for these sites can be a) local suppliers, supplying only one production site or b) global suppliers, supplying both production sites. In case a) every part needed for the final product must be produced by a least two suppliers. All global transports from suppliers of type b) are consolidated in consolidation centers before they are dispatched for the main transport (e.g. water carriage) to save logistics costs. The transport from a consolidation center to the production site depends on a fixed transportation schedule given by the operating carrier. Also, the demands of the two production sites are flexible and can go through short term changes.

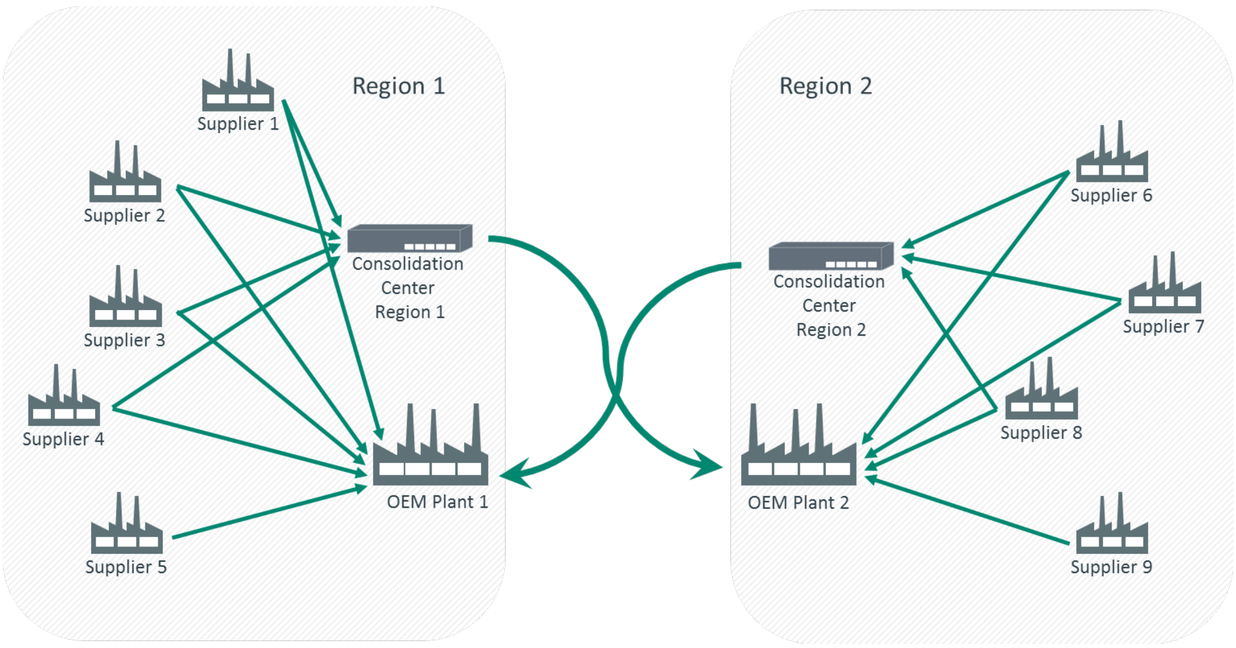


Figure 4: International Supply Network

Modeling the Planning Problem and the Planning Measures

Table 2 shows a summary of the necessary definitions for the use case in order to deploy a Virtual Experiment Field.

Type of Planning Problem	Quasi-Optimization
Target Function	Achieve a maximum of delivery reliability, i.e. satisfy all demands (D_1-D_m) for parts in the OEM plants (if possible). Achieve this at a minimum of logistics costs and capital lockup in the supply chain.
Scope	Logistical relation between fist level suppliers (S_1-S_n) and two production sites (P_1,P_2) with two alternative means of transportation in the main haul (T_1,T_2).
System Load	Parts transported between suppliers and customer
Ambient Factors	Demand of parts for every period at the OEM plants Timetables of transportation means in the main haul Capacities and order restrictions of suppliers Costs of transportation and storage Costs of capital lockup
Control Factors	Order quantity for every supplier and period Means of transportation for main haul from see (standard) to airfreight Network structure, e.g. delivery relationship between supplier and plant

Table 2: Definitions of VEF Elements for Use Case 1: International Supply Network

In a strategical or tactical planning horizon the order quantities and transportation modes can be calculated using classical deterministic programming (as demonstrated e.g. by Thorn, 2002). Deviations from these plans will occur in executive supply chain operation due to a variety of individual reasons. Typical examples that may cause short term deviations are:

- A production facility at a supplier has a breakdown and order quantities cannot be fulfilled.
- Certain materials arrive late due to a customs strike at an international see harbour.

- A quality defect is detected late and faulty material has already entered the supply chain.

A complete overview of possible deviations is given by Bockholt (2012, p. 44). As any deviation may threaten the logistical goals, operational logistics managers have a variety of possible measures at their disposition in order to fulfill the target systems. Four specific measures will be examined in this use case:

1. Change from transport see to air transport at the consolidation center and thus accelerate the material in the long haul.
2. Order additional quantities from local supplier.
3. Order additional quantities from the corresponding international supplier.
4. Order additional quantities from the other regional plant.

Implementing the Simulation Model

Focusing on the operational aspects of the logistical planning problem, the requirements for the simulation models are:

- Achieving an appropriate level of detail, i.e. calculation of daily demands of all parts and stock quantities in every supply chain section
- Integration of operational data sources, i.e. integration of timetable for see and air transports, actual demand calculation at plan etc.

Experiment Plan

Two key features of the use case can be linked together to develop the specific experiment plan:

1. The main target described by the target function is the delivery reliability; all demands of the OEM plants have to be fulfilled if possible.
2. The costs of the current situation will be the base cost, all possible measures will result in additional costs on top of the base cost.

Combining these two attributes leads to a simplification of the general optimization problem: from a cost perspective, the current situation is always the "best" situation, as further actions always entail higher costs. Only if the demands are not satisfied, actions have to be carried out. Thus, the surveillance experiment plan can be based on a bottleneck analysis.

Base version	**Material 1**	**Material 2**	**Material 3**	**Material 4**	**Material 5**	**Material 6**	**…**
Demand fulfilled	yes	yes	**no**	yes	**No**	**No**	…

Table 3: Bottleneck analysis for an example data set

The bottleneck analysis is based on the simulation of the current situation (base version). It will use the pure input data without the application of any measure.

Interpretation rules

The results of the base experiment have to be evaluated to show if all demands in the two OEM plants can be met: the sum of all stock elements at the time plus the incoming materials from all possible sources must be greater or equal to the demand of the material. If the simulation reveals that the requirements for some materials cannot be met, further experiments have to be conducted.

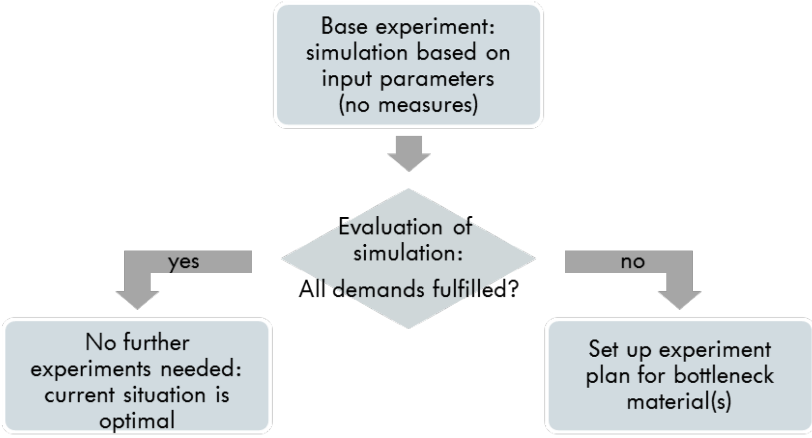


Figure 5: Interpretation rules for the base experiment

In order to simplify the experiment plan, we will assume that measures taken cannot be combined with each other. Every measure is tested with the full necessary quantity, i.e. the complete missing amount. In this case, a full factorial design is possible. Every measure can be tested and the effects and costs of every measure can be calculated with help of the simulation.

The results for the example data set of the three bottleneck materials and four measures are given in Table 4.

No	Measure	Bottleneck Material 3	Bottleneck Material 5	Bottleneck Material 6
1	Accelerate material in the supply chain	**Demand fulfilled: yes Costs: 235**	Demand fulfilled: no Costs: 435	Demand fulfilled: no Costs: 847
2	Order additional quantities from local supplier	Demand fulfilled: no Costs: 123	Demand fulfilled: no Costs: 523	**Demand fulfilled: yes Costs: 312**
3	Order additional quantities from the corresponding international supplier	Demand fulfilled: yes Costs: 346	Demand fulfilled: yes Costs: 2.234	Demand fulfilled: no Costs: 312
4	Order additional quantities from the other regional plant	Demand fulfilled: no Costs: 524	**Demand fulfilled: yes Costs: 1.312**	Demand fulfilled: yes Costs: 595

Table 4: Results of an iterative Experiment Plan

A total of thirteen simulation experiments are conducted; three different actions have to be taken for the three bottleneck materials.

Further research will be necessary to show the next steps into decision support for supply chain operations, especially on how to effectively design experiment plans for combinable measures, i.e. measures that do not cover the complete amount of bottleneck material.

5. Use Case 2: Scenario Comparison for Lean Approaches in Finished Vehicle Distribution

Lean Management is a philosophy of waste elimination, questioning processes upon their efficiency and affectivity (Ohno, 2009). These methods have been applied to a variety of areas including logistics (cp. Vijdani, Lootz, & Kirwitzke, 2010; Zylstra, 2006; Klug, 2010). Within the automotive industry, measures have been taken to adopt the lean way, yet the focus has been inbound logistics, missing to take into account the affects and implications of finished vehicle distribution. Finished vehicle distribution addresses the processes from fully build units (FBU) that are ready to be shipped until their arrival at the dealers. Although production volumes in total are quite constant, the finished vehicle distribution has to deal with a high variability in transport volumes on a transport relational basis as well as a high mean error in short-term forecasts. These two matters combined with incalculable effects of human interaction in dispatching of trucks lead to the conclusion that event-based simulation is the most suitable method to explore these processes. An application of lean methods to outbound processes leads to the question of which effect this would have on current systems. Considering the categorization identified in "Design of Virtual Experiment Fields in Logistics Planning" a scenario comparison is performed within a virtual experiment field.

Logistics Planning Problem

Following the defined process steps for setting up a logistics planning problem, first of all a target system is developed, focusing on the five high-level targets of high ecologic efficiency, low costs, high performance, high predictability and high adaptability (Klennert & Schwede, 2012). In a second step the scope of the planning problem is defined using the method of process chains (Kuhn A. , 1995, p. 37ff) to define relevant processes and boundaries. The planning problem focuses on the processes following production: the distribution of vehicles to the customer (seen in the figure on the right), particularly vehicle distribution by truck.

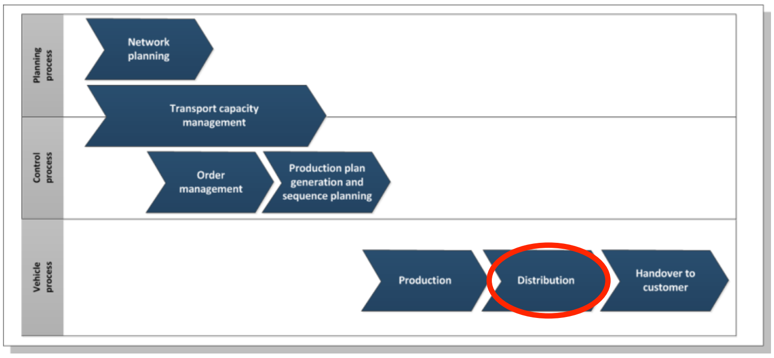


Figure 6: Processes in the Automotive Industry (following Zernechel et al. 2012)

Distribution by truck is usually carried out by one or more Logistics Service Providers (LSPs), shipping predefined loads of vehicles from the plant to a compound, where the vehicles are transshipped to dealer delivery routes. Vehicles are assigned to a specific transportation route beforehand and consolidated to loads. In a third step the system load, control and ambient factors are defined. As to be seen in Figure 6, the system load is determined by the output of production. It is comprised of all vehicles with a status "ready for shipment" and a specific destination. The control factors can be divided into two subsets. On the one hand the dispatching of trucks is adjustable, meaning that currently LSP are informed as soon as a full load is available, contractually having a certain amount of time for load pick up at their disposal. Possibilities for modification are e.g. to establish a pick-up timetable. On the other hand, currently every dealer is assigned to a compound from which he receives the vehicles. Thus another control factor is the possibility of assigning vehicles for a specific dealer to different transportation routes. Ambient factors in this planning problem are dealer locations and compound locations. The results are shown in Table 1.

Type of Planning Problem	Scenario comparison
Target function	System of objectives with main targets of high ecologic efficiency, low costs, high performance, high predictability and high adaptability
Scope	Distribution process starting at the handover from production to distribution and ending at the handover to the customer/dealer.

System Load	Vehicles produced for German market and truck distribution
Ambient Factors	Plant, compounds, and dealer locations
Control Factors	Transportation routes for individual cars, pickup-timetables

Table 5 Definitions of VEF Elements for Use Case 2: Finished vehicle distribution

Logistics Planning Measures

According to the described problem, in this specific planning problem a "transfer of methods from other application areas" is used. The measures of lean management in inbound transportation are adapted to the circumstances in outbound vehicle distribution (Klennert & Schwede, 2013). Two of the most promising measures derived are applied to the VEF processes defined in this paper: An implementation of scheduled pick-up times (constant transports) based on average historic demand (Table 6) as well as a flexible allocation of vehicles to compounds (Table 7).

Criterion	Name	Description	Range of values
Measure	Constant transports	Definition of specific timetables for load pick-up at a plant (minimum requirement: date and hour).	
Control factors	Amount of transports	Defines the number of weekly/daily transports to be scheduled	Weekly historic average (plus / minus)
	Point in time of transports	Transfers the amount of transports to specific dates	Regularly spread on a weekly basis
System load	Production orders	Fully built units (finished vehicles) with dealer affiliation	

Table 6: Logistics Planning Measure 1 "Constant transports"

Criterion	Name	Description	Range of values
Measure	Flexible allocation of vehicles to compounds	Vehicles for specific dealers are assigned two or more different route alternatives.	
Control factors	Maximum distance compound to dealer (Z)	An additional compound is only assigned to a dealer if the distance compound to dealer is less that Z.	Not in scope to 200
	Total extra kilometers from plant to dealer (Y)	An additional compound is only assigned to a dealer if total distance from plant to dealer via compound does not exceed more than Y additional kilometers compared to current route.	0 to 150
	Total extra kilometers from compound to dealer (X)	An additional compound only is assigned to a dealer if the distance from compound to dealer does not exceed X additional kilometers compared to maximum distance between that compound and its dealers currently covered.	0 to 50

System load	Production orders	Fully built units (finished vehicles) with dealer affiliation

Table 7: Logistics Planning Measure 2 "Flexible Allocation of Vehicles to Compounds"

A combination of both presented methods establishes a third measure. A process analysis of each of the three measures is made to analyze the effect on defined targets. As the scope was defined as a scenario comparison, the effect of the measures was not analyzed for an entire planning problem but for their specific effect upon the different targets within the target system. This was done by a detailed process chain analysis.

Simulation model

The two new measures are integrated into the simulation tool OTD-NET. A simulation model representing the finished vehicle distribution process is built, verified and validated containing the following objects: A plant capable of producing historical volumes as well as forecasts, 13 compounds for transit and over 400 dealer locations. As a VEF does not constitute any new approaches for building simulation models, it shall not be evaluated any further.

Experiment plan

According to the defined steps an experiment plan is established. Therefore in a first step, experiments are derived. As for all measures the entire target system is relevant, three combinations of the target systems and developed measures are possible. Thus three experiments are defined.

In a second step, the factor levels for every experiment are set. For experiment 1 (logistics planning measure 1), the factor level is determined based on an average weekly historic demand as well as a slight higher and lower amount of transports (weekly historic average plus one / minus one). For experiment 2 (logistics planning measure 2), factor levels are defined as steps of 10. For experiment 3 (combination of logistics planning measure 1 and 2), both factor levels are applied. Based on these factor levels, the complete experiment plan was defined.

In a next step, the optimized experiment plan is derived. An analysis shows that for some specific factor levels of logistics planning measure 2, the affiliated routes for all dealers are equal. This leads to a decreased amount of necessary scenarios. Moreover the scenarios are sequenced according to their need of changes in modeling.

Last, a strategy of experiments is chosen. As shown before, highly variable processes define the circumstances in finished vehicle distribution. Therefor the strategy “complete simulation” was chosen.

Interpretation rules

As the main target for scenario comparisons is to be able to compare the effects of different measures taken, interpretation rules do not necessarily affect the experiment plan or a need for any further iteration. Yet, depending on the results, different factor levels might be interesting for further analysis.

6. Conclusion and Outlook

The presented approach formalizes the proposed paradigm shift to real time planning that is enabled through Virtual Experiment Fields. By applying the presented methodology to two diverse use cases it is shown that VEF are capable of supporting design processes of Logistics

Assistence Systems. In order to increase the positive effects, the main effort in the imminent future is to enable VEF for specific industries such as the automotve sector and continue working to enlargen the scope of each VEF. Specifically, the field of optimizing experimental designs of logistics simulation models is subject to extensive research. Risk evaluation and interpretation heuristics should be detailed in additional use cases. Moreover the user base of VEF has to be widened in order to verify its effects.

7. References

Beller, M. (2010). *Entwicklung eines prozessorientierten Vorgehensmodells zur Fabrikplanung. Dissertation*. Dortmund: Technische Universität Dortmund.

Bockholt, F. (2012). *Operatirves Störungsmanagement für globale Logistikprozesse: Ökonomie- und ökologieorientiertes Referenzmodell für den Einsatz in der Automobilindistrie*. Praxiswissen Service.

Box, G., & Wilson, K. (1 1951). On the experimental Attainment of optimal conditions. *Journal of the Royal Statistical Society, Series B*, p. 1-44.

Fleischmann, B. (2007). Begriffe der Logistik, logistische Systeme und Prozesse. In D. Arnold, H. ISermann, A. Kuhn, H. Tempelmeier, & K. Furmans, *Handbuch Logistik* (p. 3-12). Berlin Heidelberg: Springer Verlag.

Gehlsen, B. (2004). *Automatisierte Experimentplanung im Rahmen von Simulationsstudien*. Aachen: Shaker Verlag.

Hellingrath, B., & ten Hompel, M. (2007). IT & Forecasting in der Supply Chain. In T. wimmer, & T. Bobel, *Kongressband 24. Deutscher Logistikkongress* (p. 281-310). Berlin: Bundesvereinigung Logistik.

Keller, M., & Hellingrath, B. (2007). Kennzahlenbasierte Wirtschaftlichkeitsberechnung in Produktions und Logistiknetzwerken. In A. Otto, & R. Obermaier, *Logistikmanagement - Analyse, Bewertung und Gestaltung logistischer Systeme* (p. 53-72). Wiesbaden: GWV Fachverlag.

Kleijnen, J. (2008). *Design and Analysis of Simulation Experiments*. New York: Springer Science+Business Media.

Klennert, M., & Schwede, C. (2012). Integrating produkction and distribution in automotive networks by a holistic system of ojectives and influencing factors. In J. Töyli, L. Johansson, H. Lorentz, L. Ojala, & S. Laari, *Nofoma 2012 - Proceedings of the 24th Annual Nordic Logistics Research Network Conference* (p. 346-362). Naantali, Finland.

Klennert, M., & Schwede, C. (7-12. June 2013). Lean management concepts for a holistic approach to a robust distribution of finished vehicles. *Proceedings of the 20th European Operations Management Association*.

Kleppmann, W. (2011). *Versuchsplanung*. München: Carl Hanser Fachbuchverlag.

Klingebiel, K. (2009). *Entwurf eines Referenzmodells für Built-to-Order-Konzepte in Logistiknetzwerken der Automobilindustrie*. Dortmund: Verlag Praxiswissen.

Klug, F. (2010). *Logistikmanagement in der Automobilindustrie. Grundlagen der Logistik im Automobilbau*. Berlin: Springer Verlag.

Kuhn, A. (1995). *Prozessketten in der Logistik - Entwicklungstrends und Umsetzungsstrategien*. Dortmund: Verlag Praxiswissen.

Kuhn, A., & Rabe, M. (1998). *Simulation in Produktion und Logistik*. Heidelberg: Springer Verlag.

Law, A., & Kelton, W. (2007). *Simulation Modeling and Analysis*. Boston: McGraw Hill.

Mößmer, H. E. & Schedlbauer, M. & Günthner, W. A. (2007) Herausforderungen der Automobilwirtschaft: Die automobile Welt im Umbruch. In: Günthner, W. A. (ed.), Neue Wege in der Automobillogistik: Die Vision der Supra-Adaptivität. Berlin Heidelberg: Springer Verlag (p. 13-17)

Ohno, T. (2009). *Das Toyota Produktionssystem*. Frankfurt, New York: Campus Verlag.

Rabe, M. (2007). *Verifikation und Validierung für die Simulation in Produktion und Logistik*. VDI Verlag.

Reeker, C., & Wagenitz, A. (2011). Analysis of Ecological Supply Chain Design Measures in the Automotive Industry. In W. Kersten, *Supply Chain, Logistics and Operations Management: International Supply Chain Management and Collaboration Practices* (p. 87-104). Köln: Josef Eul Verlag.

Santner, T. (2003). *Design & Analysis of Computer Experiments*. New York: Springer Verlag.

Schneider, I. (2009). *Die Risikobetrachtung in der Beschaffung als strategische Komponente im Supply Chain Design*. Hamburg: Shaker Verlag.

Seidel, T., Klingebiel, K. (2005): Deliverable 7.1.2 – BTO Network Design and Evaluation Methodologies and Tools. In: *Project Intelligent Logistics for Innovative Product Technologies (ILIPT)*, Project number: IST/NMP-2005-507595.

Stachowiak, H. (1973). *Allgemeine Modelltheorie*. Heidelberg: Springer Verlag.

Thorn, J. (2002). *Taktisches Supply Chain Planning: Planungsunterstützung durch deterministische und stochastische Optimierungsmodelle*. Frankfurt am Main: Europäischer Verlag der Wissenschaften.

Toth, M., & Liebler, K. (2012). Real-Time Logistics and Virtual Experiment Fields for Adaptive Supply Networks. In K. Windt, *Robust Manufacturing Control* (p. 327-340). Berlin Heidelberg: Springer Verlag.

VDI. (1997). *Richtlinie VDI 3633, Blatt 3: Simulation von Logistik-, Materialfluss- und Produktionssystemen - Experimentplanung und -auswertung*. Düsseldorf: VDI.

VDI. (2010). *Richtlinie VDI 3633, Blatt 1 Entwurf: Simulation von Logistik-, Materialfluss- und Produktionssystemen; Grundlagen*. Düsseldorf: VDI Verlag.

Vijdani, N., Lootz, F., & Kirwitzke, D. (2010). *Lean Logistics. Innovative Bewertungsmethodik zur Auswahl schlanger Materialbereitstellungsstrategien*. Universität Rostock: Logistics Journal.

Wagenitz, A. (2007). *Modellierungsmethode zur Auftragsabwicklung in der Automobilindustrie*. Dortmund: Eldorado - Lehrstuhl für Fabrikorganisation.

Weicker, K. (2007). *Evolutionäre Algorithmen*. Wiesbaden: Teubner Verlag.

Wiendahl, H., Petermann, D., & Glässner, J. (Nr. 2 1992). Application of load oriented manufacturing control in industry. *Production Planning and Control*, p. 118.

Zylstra, K. (2006). *Lean Distribution - Applying Lean Manufacturing to Distribution, Logistics and Supply Chain*. Hoboken, New Jersey: John Wiley & Sons.

The Impact of Geographic Dynamics Associated with International Expansion of Firms on Firm Strategic and Financial Performances: An Analysis of Manufacturing Emerging Market Multinationals and Global Value Chains

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Abstract

The key objective of this paper is to examine the impact of geographic dynamics on firm strategy and performance when firms pursue international expansion. We, primarily, focus on manufacturing Emerging Market Multinationals' (EMMs) mergers and acquisitions (M&As) that took place during the period of 2000-2012. EMMs considered in this study are listed in the United Nations' UNCTAD world investment report (2000-2012), as the top 100 non-financial Transnational Corporations (TNCs) from emerging market and developing countries, including the regions of Latin America, Sub-Saharan and North Africa, Central, Eastern and Southeastern Europe and West, South and South-east Asia. The paper is divided into two main dimensions. First dimension examines the impact of geographic dynamics and variations, which includes an array of features ranging from economic to socio-cultural factors, of host countries on EMMs. Both the dynamics and variations are observed individually as host county factors and a methodology of principal component analysis, along with several geographic models, is integrated in order to analyze strategic performances of EMMs. The second dimension engulfs the examination of EMMs' financial performances with the incorporation of logistic regression analysis so as to discern the value implications to firms. Hence, the analyses of both of these dimensions are integrated to cohesively configure the intra and inter - relations of firm global value chains.

Keywords: International Expansion; Geographic Factors in International Expansion; International Finance; Mergers and Acquisitions; Manufacturing Firms; Emerging Market Multinationals; Firm Value

I- Introduction

Internationalization of multinational corporations (MNCs) is not a new phenomenon. Since the 1970s MNCs from the developed countries have been expanding their operations whether the goal is manufacturing, sourcing or some other value operation/s. In recent years, MNCs from the emerging markets and/or developing economies (EMMs) have begun to appear in the playing field. Like their counterparts from the developing world, they began to internationalize their operations based on their goals and strategies - be it resource seeking or market expansion they became integrated into the globalization seen. Their geographic expansion and global value chain activities have evolved over the years and began including strategies, such as joint ventures, strategic alliances and mergers and acquisitions.

Hence, the main goal of this paper is to examine the strategic patterns of internationalization of EMMs and whether these geographic expansions fall into any of the globalization vs. regionalization classifications, which has been profoundly debated on in recent years. In doing so, we focus solely on internationalization activities of EMMs through mergers and acquisitions (M&As). First, we utilize 841 M&A announcements of manufacturing EMMs during the time period of 2000- 2012 in order to analyze their patterns of expansion. We mostly inquire about geographic factors in terms of regional vs. global. In this fashion, we also explore whether they differ from their developed country counter parts. Since most research involving globalization vs. regionalization focuses on developed country MNCs and not so much on emerging market/developing economy EMMs, we raise the following questions: Do EMMs follow the same patterns as their developed country counterparts? How and where do they operate global value chains? Are the global value chain activities of EMMs' cross-border expansion activities really global? What are the locations of the following activities (global or regional)? Research and development; Procurement and Sourcing; Manufacturing; Marketing; Distribution, and Sales and Services.

Second, we explore the degree of financial performance and whether there is value creation for these firms in pursuing their strategic patterns. Hence, we attempt to ascertain the degree of correlation between global or regional strategy and financial performance and ask the following questions: Do EMMs that operate globally have sound financial performance results? And, do EMMs that operate globally have sound financial performance results?

II- Literature Review

a- Global or Regional Geographic Expansion and Mergers and Acquisitions

Mergers and Acquisitions trends throughout the internationalization process have resulted in a changing of the landscape of many industries, especially the manufacturing sector. The large organizations created throughout the globalization process have a profound ability to impact various aspects of the global economy (Van Cap, 2000). Such mergers and acquisitions also impact the extent to which these largest MNCs are regionalized rather than globalized. Recent research shows that MNCs located in the triad regions merge and acquire with other MNCs in these regions. Hence, they are captured within the structure of the home base located in the triad region as suggested by Rugman (2001).

Rugman eloquently suggests that globalization that the economic world is witnessing today is actually nothing more than regionalization. Suggesting that the international expansion of firms, in reality, occurs in a Triad System. To the extent that MNC activity is focused within the triad regions as identified by Rugman such activity does appear to be primarily regionalized as opposed to globalized. In fact, Rugman questions the use of the term globalization if MNEs strategize in a regional fashion (i.e. triad markets of North America, the European Union, and Japan) and act locally (Rugman 2001).

However, the concept of globalization is continually evolving. Kenichi Ohmae (1985) describes the triad as a geographic region consisting of the United States, the European Union and Japan that shares several commonalities. These commonalities, such as low macroeconomic growth, similar technological infrastructure, presence of large capital and knowledge-intensive firms, etc., lead the triad to claim the largest share of innovations and largest markets for most new products. Most of the world's largest MNEs have their headquarters in one of the triad regions. One problem that Ohmae (1985) identifies with these triad regions is that they sell engineered commodities (e.g. innovative and differentiated products) that lose their monopoly status quite quickly. As such, these products can create challenges when attempting to engage in foreign markets even in other triad regions. Given such challenges, Ohmae (1985) suggests consortia and joint ventures when approaching the other triad regions and further suggests a perspective where a corporate center is located in one region of the triad and mentally located equidistant from the economic and political power bases in the triad regions. What Ohmae (1985) did not anticipate was the extension of the triad to the "broad" triad of today which encompasses NAFTA, the EU and Asia as well as other relevant trade agreements impacting triad behavior.

Rugman (2001) considers Ohmae's strategy and whether these large MNEs of the world have implemented the suggested strategy by focusing on sales as a measure of success. He argues that relative sales dominance of the largest MNEs in particular markets (i.e. the triad markets) demonstrates that these firms are in fact not "globalized" as their products are not truly accessible and attractive across a wide global market. Additionally, these findings demonstrate limitations to the transferability of Firm Specific Advantages. If, in fact, different competitive strategies are required in different global markets then a truly global mindset would be difficult if not impossible to achieve.

It is crucial to point out here that most of the research in this area has been concerning MNCs form the developed economies and not necessarily focusing on the MNCs from the developing economies and/or emerging markets. Hence the following questions can be raised: Do they follow the same patterns as their counterparts? However, recent research has started to examine this area. In this paper, we focus on internationalization of these multinationals.

How and where do they operate global value chains? Are the global value chain activities of EMMs' cross-border expansion activities really global? What are the locations of the following activities (global or regional)? Research and development; Procurement and Sourcing; Manufacturing; Marketing; and Distribution; as well as Sales and Services.

b- Geographic Factors and industry classification:

Hence, most research in this area supports Rugman and advocates that internationalization through regionalization embrace almost all types of MNCs that operate in high-fixed cost industries to financial sectors (Rugman and Verbeke, 2004;

Dunning *et al*., 2007). On the contrary, other research offers a different view suggesting that service MNCs have more tendencies to operate regionally and close to home region as opposed to manufacturing firms that tend operate in a more global strategic posture (Beleska-Spasova and Glaister, 2009).

Due to the ever-changing exogenous factors, such as geographic, and political and their impact on MNCs strategic and business plans Rugman (2001) states that a vast majority of manufacturing and service activity is at the heart of business networks based on a regional strategy employed by the triad. Clusters of value-added activities are formulated and implemented by multinational enterprises originating from these countries. A staggering +80 percent of global stock of FDI and over half of world trade comes from this triad engine. This may be the reason for the perception that Ohmae may be ignoring the other 20 percent of global manufacturing and service activity when it is driven by the triad. Rugman even goes as far to state that we don't really have a global economy, but a "triad-based regional one".

Rugman in his book, "The End of Globalization". Multinationals from these three countries dominate international production across major industries. Much of the technological innovations from these firms assist with increasing the standard of living in target markets as well as offering regionalized products as influenced by trade. Mergers and Acquisitions are largely intra-triad. Nations representing this other 20 percent rely on the triad to obtain global status. But, how does this apply to multinationals from the emerging markets and their industry dynamism?

Industry dynamism refers to environmental instability and the extent to which the organization is affected by changes in the industry. Can success be determined before expansion by matching their industry to the host country? Rugman and Oh (2007) and Schlie and Yip, 2000) has shown that being more regional than global depends on the industry a firm may be involved in. By applying all of this to the internationalization of EMMs, contribution of this research will be able to identify the following: Firms operate in what industries are better off to hold a disperse location internationalization strategy? And vice – versa? Similar research based on US MNCs posits that firms that involve in more *technologically-complex goods* operate in a global venue as it is essential for these goods to have global production chains (Keller and Yeaple, 2008). High-tech orientation decreases MNCs' home-region orientation (Cerrato, 2009).

Yet, other research suggests high-tech trade is more global in the EU and NAFTA than lower or non-high-tech sectors (Curran and Zignago, 2012). This research may overall suggest the indication of a relationship with knowledge intensity. Similarly, research on internationalization of knowledge related sectors emphasizes that higher knowledge intensity does not necessarily result in strong home-region orientation (Verbeke and Kano, 2012).

EMM categorization

Industry Categorization:

OECD categorizes industries in a general fashion between high-tech, high medium tech, low medium tech and low tech (OECD, 2011). Similarly, in this paper we categorize manufacturing industries, but we only differentiate between hi-tech and none hi-tech. Hi-tech is considered as the higher knowledge intensity of the manufacturing sector. Most EMMs included in the hi-tech classification also include the following:

Emerging industries: Digital life, high-tech services, intelligent vehicles, health care, and green industries.

Emerging technologies: Broadband communications, Internet multimedia, digital content, system-on-a-chip (SoC), radio frequency identification (RFID), vehicle energy conservation, remote diagnosis, green energy, and green materials. These technologies also include flexible electronics, intelligent robots, biomedicine, and nano-technology.

New Technologies: Environmentally friendly construction materials, building energy conservation, soft materials, image display, precision machinery, medical equipment, bio-pharmacology, genetic medicine, and nano- materials.

EMMs that are classified as none hi-tech are the ones that operate in general manufacturing sectors.

In order to identify the industry sectors and to construct a valuable contribution to EMM literature we used SIC codes of various manufacturing sectors.

Geographic categorization / orientation: We do this in two configurations:

1- To be able to assess the difference between regional and global expansion, we differentiate between the regions of the world. Hence, when we classify a global expansion M&A announcement, it means the EMM internationalizing into regions which are not proximate to its home region. Similarly, when we classify a regional expansion M&A announcement, it means that the EMM internationalizing into regions which are proximate to its home region.
2- We also identify regions as dynamic and less dynamic regions based on socio-cultural and geo-political locations.

Firms that operate in more dynamic and uncertain environments may be at advantageous to operate in geographically diffused mode.

c- Financial performance

Rugman (2005 and 2010) suggest many large MNCs are not generating profit globally but mainly from operating in their own region; thus, MNCs' shareholder wealth may be more determinable based on their regional foreign activities rather than their foreign activities outside their regional bloc. However, Buckley and Ghauri (2004) suggest there is conflict between markets, which is caused by different pace of global integration. According to Buckley and Ghauri (2004), financial markets are mostly globalized, although each country's financial market might be viewed individually; goods and service markets have lower speed of integration and are still within regional level, while Buckley et al. (2001) points out that labor markets function individually within nations. However, Berg and Guisinger (2001) discusses that financial markets differentiate in term of their locations. In other words, although financial markets should be reflecting all the information from the world, there information may not be weighted equally in different markets. Furthermore, Khanna et al. (2006) suggested that globalization would make firms to adopt advance corporate governance standards, although implementation on these standards will be a question. By using single country as receiver of MNCs' foreign investment, we can assume that both MNCs and their shareholders should have the same information from the target market in order to reduce risk.

Although geographic diversification and or internationalization relates to better market share and to better financial performance, firm's success heavily relies on supply networks and the position of its value chain activities. Recent literature that focuses on firm performance and internationalization began to debate on performance of firms by comparing firms that adopt a global strategic orientation with firms that concentrates on regional approach (Hitt *et al.,* 2006; Rugman *et al*., 2008). Hence, research suggests that financial performance is positively associated with regionalization due to legal, economic and cultural proximity (Qian *et al*.,2008), and reduction of administrative cost (Rugman, 2005).

However, other studies show that addressing the issue from the firm and industry level may suggest positive correlation between financial performance of the firm and the characteristics of the industry it may be pursuing (Thomas, 2005; Hitt *et al*., 2006). Research on performance further suggests that intra-regionally diverse firms reveal a positive and a linear correlation with firm performance. On the other hand, other research show an inverted U-shaped performance relationship when global firms are concerned. (Qian *et al*., 2008).

We address these issues from the perspective of EMMs global and regional operations.

III- Data and Methodology:

Data

We, primarily, focus on publicly listed large manufacturing EMMs' mergers and acquisitions that took place during the period of 2000-2012. EMMs considered in this study are listed in the United Nations' UNCTAD world investment report (2000-2012), as the top 100 non-financial Transnational Corporations (TNCs) from emerging market and developing countries, including the regions of Latin America, Sub-Saharan and North Africa, Central, Eastern and Southeastern Europe and West, South and South-east Asia.

We obtained M&A data from SDC platinum and company financial data form Data Stream.

Methodology

Method 1: We designated twelve business factors of global and regional expansions to explore their relationship with the financial performance in the internationalization process of manufacturing EMMs. We later transformed these twelve factors into four dimensions (principal component factors) using the method of factor analysis. By employing the categorical regression method, we examined the relationships between return on sales (ROS), return on assets (ROA) and the four designated dimensions.

Method 2:

Dependent variable

For firm performance we used ratio of return on sales (ROS) and measured it as the two-year average ratio of return to evaluate financial performance of the firm (Ruigrok, Georgakakis and Greve, 2013; Capar and Kotabe, 2003). However, we also integrated return on assets (ROA) as a dependent variable. The results obtained were similar (Hitt *et al*. 1997).

Independent variables

Based on the research of (Ruigrok, Georgakakis and Greve (2013), we used degree of regionalization (DOR) as one of the measures to examine the level of operations or rather foreign sales within its home region relative to its domestic sales. DOR is calculated as it follows:

[1- (Domestic Sales)/(Regional Sales + Domestic Sales)] – [1- (Domestic Sales)/(Global Sales + Domestic Sales)]

We later performed logistic regression analysis.

IV - Results and Conclusion

Findings – Our findings reveal that unlike developed country MNCs, EMMs prefer to internationalize through M&As by mostly focusing on global cross-border expansion more than regional expansion marketing capability of firms plays the most important role in improving performance of firms that embrace internationalization. In addition, these expansion activities are in triad regions. Hence, all of these findings suggest that this behavior is different that developed nation counterpart and not necessarily in agreement with previous research.

The results also suggest that hi-tech EMMs prefer global expansion through M&As as opposed to none hi-tech manufacturing firms, which mostly prefer regional expansion. This finding may be in line with previous research.

The results are indicative in the following table and the graphs located in the appendix:

As table 1 indicates out of 841 M&A announcements, 478 are global expansion (as previously defined as expanding into another region/s not proximate to firm/s home region. Hence, the number of regional expansions is 137. Globally expanding hi-tech EMMs constitute 59.57 percent and regionally expanding hi-tech firms constitute 40.43 percent. Globally expanding none-hi-tech firms constitute 55.81 percent and regionally expanding none hi-tech firms constitute 44.19 percent.

Finally, manufacturing EMMs that internationalize through a global M&A expansion strategy perform better than the regionally expanding manufacturing EMMs. This result is also supported by various previous research in this field.

Table 1:

	HI-TECH	NONE-HI-TECH	SUBTOTAL/TOTAL	HI-TECH EMMS GOING GLOBAL (%)	HI-TECH EMMS GOING REGIONAL (%)	NONE HI-TECH EMMS GOING GLOBAL (%)	NONE HI-TECH EMMS GOING REGIONAL (%)	HI-TECH EMMS TOTAL (%)	NONE-HI-TECH EMMS IN TOTAL (%)
GLOBAL	137	341	478	28.66%	71.34%				
REGIONAL	93	270	363			25.62%	74.38%		
SUBTOTAL/TOTAL	230	611	841					27.35%	72.65%
HI-TECH EMMS GOING GLOBAL (%)	59.57%								
HI-TECH EMMS GOING REGIONAL (%)	40.43%								
NONE HI-TECH EMMS GOING GLOBAL (%)		55.81%							
NONE HI-TECH EMMS GOING REGIONAL (%)		44.19%							
EMMS GOING GLOBAL IN TOTAL (%)			56.84%						
EMMS GOING REGIONAL IN TOTAL (%)			43.16%						

References

Aggarwal, R., Isil Erel, René M. Stulz, and Rohan Williamson, (2009) 'Do U.S. firms have the best corporate governance? A cross-country examination of the relation between corporate governance and shareholder wealth', *Review of Financial Studies*, forthcoming.

Aharoni, Y. (1966). 'The Foreign Investment Decision Process'. *Harvard Business School, Boston, MA*.

Balakrishnan, S., & Koza, M. P. 1993. Information asymmetry, adverse selection, and joint ventures. *Journal of Economic Behavior and Organization,* 20: 99– 117.

Bauer, R., Frijins, B., Otten, R., and Tourani-Rad, A. (2008) 'The impact of corporate governance on corporate performance: Evidence From Japan', *Pacific-Basin Finance Journal*, 16:236-251.

Berg, D.M. and Guisinger, S.E. (2001) 'capital flows, capital controls and international business risk'. In A.M. Rugman and T.L. Brewer (eds.) *The Oxford Handbook of International Business*, Oxford University Press: Oxford, pp: 259-281.

Bleeke, J. and Ernst D. (1993). 'Collaborating to Compete: Using Strategic Alliances and Acquisitions in the Global Market Place'. *Mckinsey*.

Borde, S.F.; Whyte, A.M.; Wiant, K.J; and Hoffman L.L. (1998). 'New evidence on factors that influence the wealth effects of international joint ventures'. Journal of Multinational Financial Management 8: 63-77.

Brown, L. and M. Caylor,(2006) 'Corporate Governance and Firm Operating Performance,'Journal of Accounting and Public Policy 25:. 409–434.

Buckley, P.J. and Casson, M. (1976) The Future of the Multinational Enterprise, *Macmillan*: London.

Buckley, P.J.(1989), 'Foreign Direct Investment by Small- and Medium-Sized Enterprises: The Theoretical Background'. *Small Business Economics*, 1(2) 89-100 (reprinted in Peter J Buckley. 1989. The Multinational Enterprise: The theory and Application, Basingstoke: Macmillan)

Buckley, P.J. and Chauri, P.N. (2004), 'Globalization, economic geography and the strategy of multinational enterprises'. *Journal of International Business Studies* 35: 91-98.

Buckley, P.J., Clegg, J., Forsans, N. and Reilly, K.T. (2001) 'Increasing the size of the country: regional economic integration and foreign direct investment in a globalized world economy'. *Management International Review* 41(3): 251-274.

Buckley, P.J., Clegg, J., Cross, A.R., Voss H. and Zheng, P., (2007) 'The determinants of Chinese outward foreign direct investment'. *Journal of International Business Studies* 38 (4) (2007), pp. 499–518.

Chen, H. Y., Hu, M. Y., & Shieh, J. C. P. 1991. The wealth effect of international joint ventures: The case of U.S. investment in China. *Financial Management,* 20(4): 31–41.

Cheng, L., Fung, J. and Lam, K. (1998) 'An examination of the determinants of stock price effects of US–Chinese joint venture announcements', *International Business Review* 7: 151–161.

Cheng, S., and Firth, M. (2005) 'Ownership, Corporate Governance and Top Management Pay in Hong Kong', *Corporate Governance*, 13(2): 291-302.

Cheung, Y. L., Connelly, J. T., Limpaphayom, P. and Zhou, L. (2007) ' Do investors really value corporate governance? Evidence from the Hong Kong market', Journal of International Financial Management and Accounting 18(2): 86-121

China: Investment regulations. (2011). *Economist intelligence unit*. Retrieved June 1, 2011, from http://viewswire.eiu.com.ezproxy.snhu.edu/index.asp?layout=VWPrintVW3&article_id=457858630&printer=printer.

Claessens. S. and Fan. J. P. H. (2002) 'Corporate governance in Asia: A survey', International Review of Finance 3(2): 71-103.

Clarke, D. C. (2003) 'Corporate governance in China: An overview', *China Economic Review*, 14: 494-507

Crutchley, C. E., Guo, E., & Hansen, R. S. (1991). Stockholder benefits from Japanese–U.S. joint ventures. *Financial Management*, *20*(4), 22–30.

Das, S.; Sen, P. K.; and Sengupta, S. (1998). 'Impact of strategc alliances on firm valuation'. *Academy of Management Journal* 41: 27-41

Doukas, J., and Travlos, N.G. (1988). 'The effect of corporate multinationalism on shareholders' wealth: Evidence from international acquisitions'. *Journal of Finance* 43 (December): 1161-75

Dunning, J. H. (1979). 'Explaining Changing Patterns of International Production: in Defense of the Eclectic Theory'. *Oxford Bulletin of Economics and Statistics*, 41:269-295.

Dunning, J. H. (1988). The eclectic paradigm of international production: A restatement and some possible extensions. *Journal of International Business Studies*, 19, 1988, 1-31.

Gugler, K., Mueller. D.C. and Yurtonglu, B.B., (2004) 'Corporate governance and globalization', Oxford Review of Economic Policy 20(1): 129-156.

Guille′n, M.F.: 1999, Corporate Governance and Globalizatin: Arguments and Evidence against Convergence (Working paper, Wharton business School).

Gupta, A., McGowan Jr, C. B., Misra, L. and Missirian, A., (1991). 'Gains from corporate multinationalism: evidence from the China experience'. *The Financial Review* 26 3, pp. 387–407

Harvey, C. R., (1993). 'Portfolio enhancement with emerging markets and conditioning information, in Stijn Claessens and Sudarshan Gooptu, Eds.: *Portfolio Investment in Developing Countries* (World Bank, Washington, D.C.), 110-144.

Huang, B. W. S. and Zhang, X. (1996). 'Determinants of the degree of ownership in equity joint ventures in China'. Hong Kong Baptist University, Working Paper.

Hymer, S. H. (1960): "The International Operations of National Firms: A Study of Direct Foreign Investment". PhD Dissertation. Published posthumously. *The MIT Press*, 1976. Cambridge, Mass.

Jensen, M. C., and W. H. Meckling (1976), `Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure', *Journal of Financial Economics*, 3, 305±60.

Johanson, J., and Vahlne, JE. (1992) 'Management of Foreign Market Entry' *Scandinavian International Business Review*, 1(3): 9-27.

Kahiey, W. (1987). 'Direct investment activity of foreign firms. *Economic Review*, Federal Reserve Bank of Atlanta, Summer 1987.

Khanna, T, and Palepu, G., K. (2010). Winning in emerging markets: a road map for strategy and execution. *Harvard Business School Pr*.

Khanna, T., Kogan, J., and Palepu, G. K. (2006) 'Globalization and Similarities in Corporate Governance: A Cross-Country Analysis', *The Review of Economics*

and Statistics, 88(1): 69-90.
Kogut, B. (1983) 'Foreign direct investment as a sequential process'. In Kindleberger, C. and D. Audretsch (eds), *Tlze Mulltinational Corporation in the 1980s.* MIT Press, Cambridge.
Kogut, B. (2003) 'Globalization and context', Keynote Address at the First Annual Conference on Emerging Research Frontiers in International Business, Duke University, March.
Koh, J. and Venkatraman, N. (1991). 'Joint venture formations and stock market reactions: An assessment in the information technology sector'. *Academy of Management Journal* 34: 869-892.
La Porta, R., F. Lopez-De-Silanes and A. Shleifer (1999), `Corporate Ownership around the World', *Journal of Finance*, 54, 471-518.
Lee, I., & Wyatt, S. B. (1990). The effect of international joint ventures on shareholder wealth. *The Financial Review*, *25*(4), 641–649.
Mathur, I. and Waheed, A. (2011) 'Overseas Expansion and Shareholders' Wealth', *Journal of Applied Business Research* 7(4): 48-55.
Morgan, R.E. and Katsikeas, C.S. (1997). ``Theories of international trade, foreign direct investment and firm internationalisation: critique'', *Management Decision*, January/ February, Vol. 35, parts 1 and 2, 68-77.
O'Grady, S., & Lane, H. W. (1996). The psychic distance paradox. *Journal of International Business Studies*, 27: 309–333.
Peng, M.W., Wang, D.Y.L., & Jiang, Y. (2007) An institution-based view of international business strategy: A focus on emerging economies. *Journal of International Business Studies*, 39(5): 920–936.
Qian, Yingyi and Jinglian Wu, "China's Transition to a Market Economy: How Far Across a River?," in Nicholas Hope, Dennis Tao Yang, and Mu Yang Li, eds., How Far Across the River: Chinese Policy Reform at the Millennium, Stanford: *Stanford University Press*, 2003, pp. 31–63.
Rivoli, P., and Salorio E. (1996). Foreign direct investment and investment under uncertainty. *Journal of International Business Studies* 27:335-357.
Rugman, A. M. (1976). 'Risk Reduction by international diversification'. *Journal of International Business Studies*, 75-80
Rugman, A. M. (1981). '*Inside the Multinationals: The Economics of Internal Markets*', New York: Columbia University Press.
Rugman, A. M. (2000) '*The End of Globalization'*, Random House: London.
Rugman, A. M. (2005) '*The Regional Multinationals: MNEs and Global Strategic Management*', Cambridge, UK: Cambridge University Press.
Rugman, A. M. (2010). Theoretical aspects of MNEs from emerging economies. In R. Ramamurti (Ed.), *Emerging Multinationals in Emerging markets* (pp. 55-63). Cambridge: Cambridge Universit Press.
Rugman, A. and Hodgetts, R. (2001) The end of global strategy. *European Management Journal* 19, 333–343.
Rugman, A. M., and Oh, C. H. (2007) 'Multinationality and Regional Performance, 2001-2005', in A.M. Rugman (ed.), Regional Aspects of Multinationality and Performance, Research in Global Strategic Management series, Oxford, UK: Elsevier, 13: 31-43.
Schut G. and Frederikslust R. van. (2004). 'Shareholders Wealth Effects of Joint Venture Strategies'. Multinational Finance Jurnal, Vol. 8, no. 3 & 4, 211-225.
Seiler, J. M. (2004). *Performing financial studies: a methodological cookbook.* Pearson College Div

Shapiro, A. C. (1992). '*Multinational financial management'*. (4th ed.) Allyn and Bacon

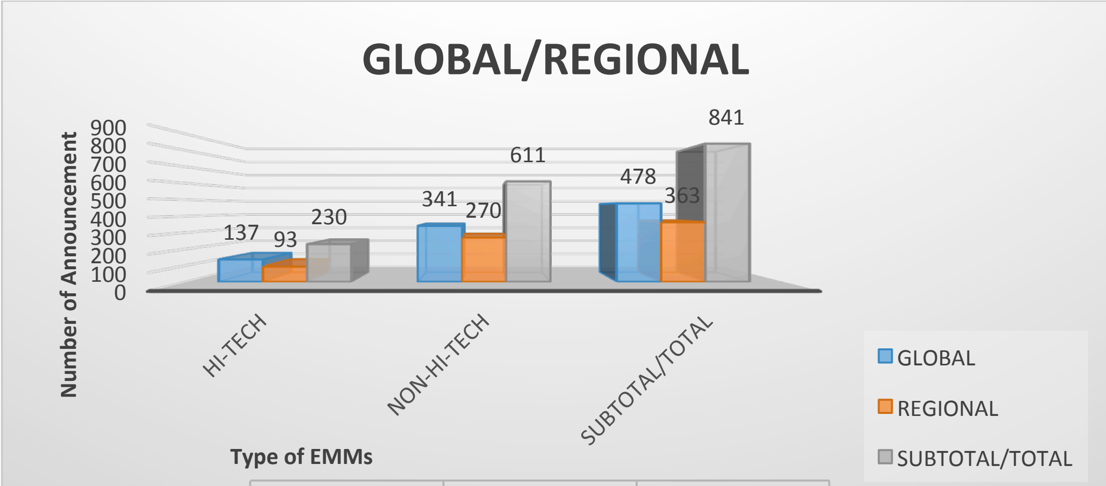
Shleifer, A., and R. Vishny (1997), `A Survey of Corporate Governance', *Journal of Finance*, 52, 737-783.

Slideri, S. (1997). 'Globalization and regional integration'. *European Journal of Development Research* 9(1):28-91

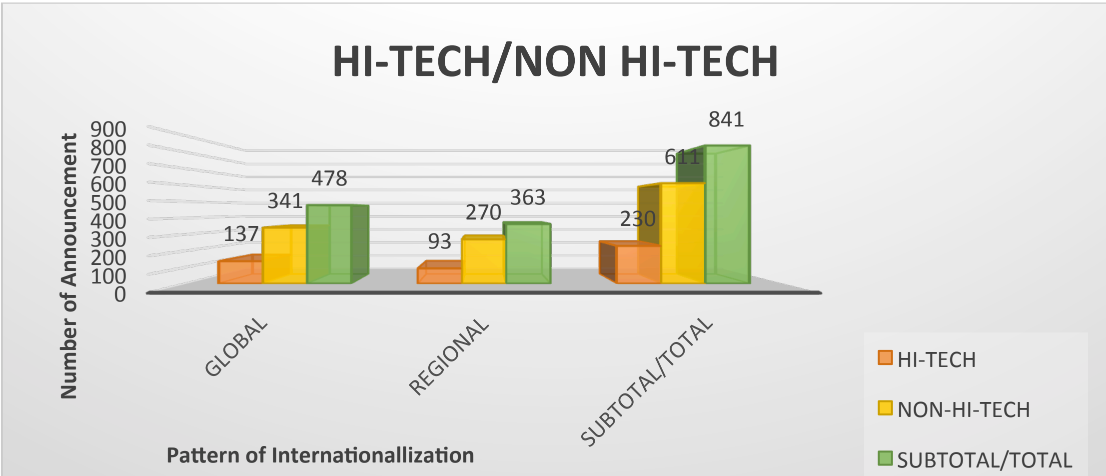
Tong, T. W., Reuer, J. J. and Peng, M. W. (2008) 'International joint ventures and the value of growth options', Academy of Management Journal 51(5): 1014-1029.

Xu, X., and Wang, Y. (1999) 'Ownership structure and corporate governance in Chinese stock companies', *China Economic Review*, 10:75-98

Zhou, L. and Ho, K. (2010) 'Diversification, Partner Relatedness, and Shareholder Value of International Joint Ventures.' *23rd Australasian Finance and Banking Conference* 2010 Paper, August 23rd.



	HI-TECH	NON-HI-TECH	SUBTOTAL/TOTAL
GLOBAL	137	341	478
REGIONAL	93	270	363
SUBTOTAL/TOTAL	230	611	841



	GLOBAL	REGIONAL	SUBTOTAL/TOTAL
HI-TECH	137	93	230
NON-HI-TECH	341	270	611
SUBTOTAL/TOTAL	478	363	841

The results indicate that EMM's pattern of internationalization is different than that of developed country multinationals as indicated by Rugman. The pattern of developed country multinationals have mostly been regional within the TRIAD system.

A literature-based state of the art review on the identification and classification of supply chain design tasks

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Abstract

Supply chain design (SCD) integrates long-term and strategic decisions on the configuration, planning, and management of supply chains. However, this subfield of supply chain management remains loosely defined and the common understanding of SCD varies widely among authors. This paper seeks to analyse current literature on SCD in order to contribute to a common definition of SCD and a classification of the tasks carried out in SCD.

In a first step, a comprehensive review of standard SCM literature is conducted to identify different definitions and understandings of supply chain design as well as the SCD tasks described therein. As a result, a framework for the classification of SCD tasks, the "Supply Chain Design task model", is introduced. In a second step, a review of contemporary high-ranked journal articles on SCD has been carried out in order to validate the framework and classify recent research in the field of SCD.

Keywords: Strategic Network Planning, Supply Chain Configuration, Supply Chain Design, Supply Chain Management, Supply Chain Task Model

1. Introduction

Supply chain design (SCD) is the subfield of supply chain management (SCM) that integrates long-term and strategic decisions on the configuration, planning, and management of supply chains (Chopra and Meindl, 2010; Simchi-Levi et al., 2009). Several major trends such as the on-going globalisation, shorter product life cycles, and innovative technologies have a significant impact on companies and their supply chains. Subsequently, supply chains need to be reconfigured more frequently. For each reconfiguration of the supply chain network, many interdependent and complex SCD tasks need to be processed (Bertsch and Nyhuis, 2011; Klingebiel et al.). However, nowadays companies lack an entire understanding of SCD tasks. Various tasks in designing a supply chains such as facility location or the allocation of products to markets are being carried out independently. This leads to a fragmentation of data, efficiency losses due to inconsistencies between different IT systems and a lack of reconcilement between different planning departments. Consequently, double-planning and inconsistencies in the results are not unusual.

These challenges ask for a holistic approach to SCD in order to achieve effectiveness and efficiency in planning processes and the supply chain structure itself. IT systems and tools need to be combined in an appropriate way to achieve a permanent readiness to reconfigure the supply chain structure. Therefore, in a first step, SCD tasks need to be gathered and structured in order to gain a consistent understanding of what a holistic SCD planning method and appropriate IT tools should be handling with.

However, even in research, the field of SCD remains loosely defined and the common understanding of SCD varies widely among authors. Furthermore, SCD is increasingly enriched by new fields of research like risk management, robustness or environmental aspects (Chopra and Meindl, 2010, pp. 163 ff; Simchi-Levi et al., 2009, pp. 317–323; Klingebiel and Li, 2012; Cirullies et al., 2012). Consequently, research lacks a clear definition of SCD itself as well as of its tasks, their mutual differentiation and the identification of implicitly included subfields of research. Due to the unclear definition of SCD and a missing detailed structure of its tasks, the first research question aims to create a common understanding of SCD and an elementary structure of SCD tasks:

1. Which tasks does supply chain design comprise and how can they be structured appropriately?

Based on this structure, the second research question creates the link to the contemporary understanding and prioritisation of SCD tasks:

2. On which tasks does research focus on today and which new fields of research in SCD can be identified?

In order to generate a common understanding of SCD and to derive, delineate and classify SCD tasks, a systematic, evidence-informed review and content analysis has been conducted on the current SCD research literature. The paper is structured as follows: Section 2 answers the first research question by classifying supply chain design as part of SCM and provides a first approach to the classification of SCD tasks based on a review of major books on SCM and SCD. The second research question is answered in section 3 based on a review on contemporary journal articles. The last section highlights the findings and provides an outlook to their implications on research as well as practice.

2. Identification of supply chain design tasks

To obtain a common understanding of SCD, the first subsection introduces key terms and provides a short integration of SCD into the wider field of SCM. In order to derive a scientifically approved structure of SCD tasks, a textbook review was conducted. The second subsection lines out the applied methodology for the review. In the following subsection the findings are presented in detail. The last subsection finishes this section with an intermediate summary by presenting the structure of SCD tasks and answering the first research question.

2.1. Characterisation of supply chain design within supply chain management

SCM is considered as “the management of upstream and downstream relationships with suppliers and customers to deliver superior value at less cost to the supply chain as a whole” (Christopher, 2005, p. 5). The significance of cooperation increases today as the vertical range of manufacture is being reduced and the number of echelons is increasing (Plümer, 2003, p. 125). Supply chains are following a strategy which is directly supporting an enterprise’s success and, thus, should follow the overall company strategy (Cohen and Roussel, 2006). The accordance of company and supply chain strategy is called the “strategic fit” (Chopra and Meindl, 2010, p. 39). According to Chopra and Meindl, the supply chain strategy should be oriented by a company’s competitive, marketing and product development strategy.

The management of supply chains with the objective to reach the described strategic fit is increasingly complex as network partners are exposed to various requirements and make autonomous decisions whose impacts are perceived in the network at different locations at different points in time (Keßler et al., 2010, pp. 7–9). A renowned example is the “bullwhip effect”, which describes the impact of minor changes in demand at the end of the supply chain leading to increasing demand fluctuation at the upstream supply chain echelons (Lee et al., 1997). SCM tasks are accordingly comprehensive. Nevertheless, they can in a first step roughly be categorized based on their planning horizon and impact. Typically, SCM tasks can be classified in three decision levels (Kuhn and Hellingrath, 2002, p. 143; Simchi-Levi et al., 2009, p. 12; Chopra and Meindl, 2010, pp. 25 f.):

- *Supply chain design*: Strategic level, tasks and decisions with long-term impact
- *Supply chain planning*: Tactical planning level, decisions with mid-term impact such as quarterly reviewed tasks
- *Supply chain operations*: Operational decision level, decisions affecting short-term planning such as day-to-day scheduling of distribution routes

Besides this rough classification, the tasks are further structured by the help of SCM models. Examples of these models are the House of SCM (Stadtler, 2002, p. 10), the Supply Chain Planning Matrix (Meyr et al., 2002, p. 99) and the SCM task model (Kuhn and Hellingrath, 2002; ten Hompel and Hellingrath, 2007). As the last-mentioned model, which is displayed in Figure 1, covers SCM tasks in breadth and comprises a detailed description of its elements while following the three-level-approach, it is preferred to line out the role of SCD within SCM.

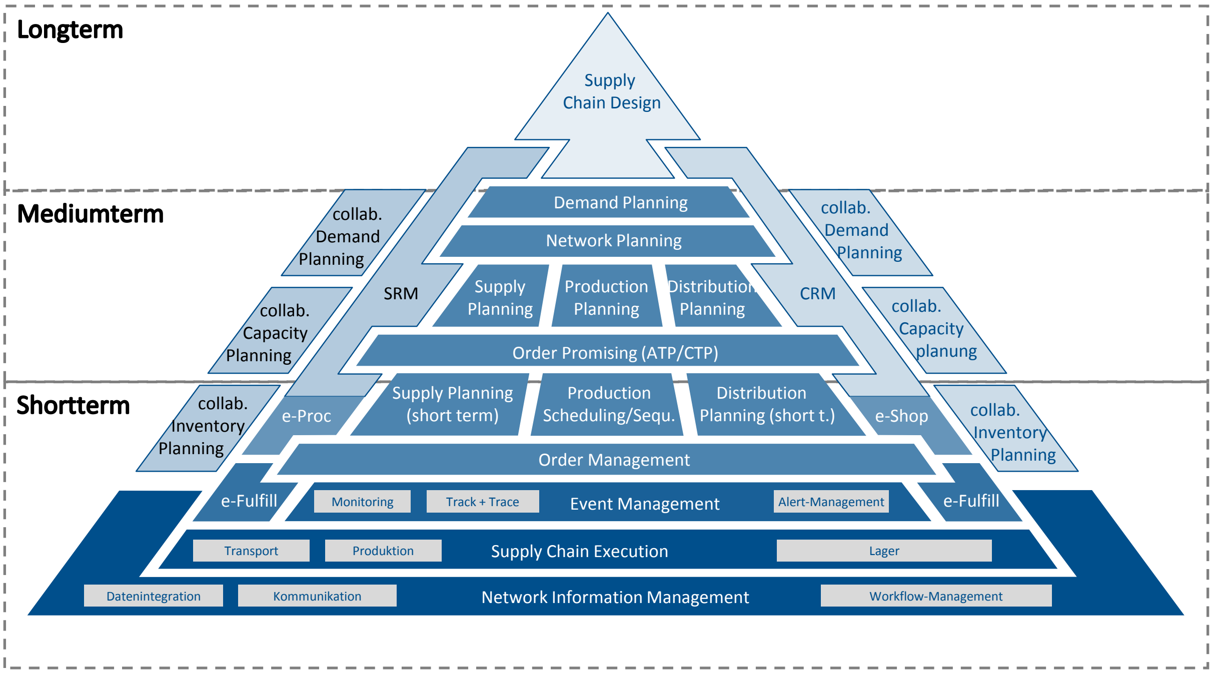

Figure 1: SCM Task Model (Kuhn and Hellingrath, 2002, p. 143)

The SCM task model is classified by two dimensions: the horizontal axis indicates, in accordance with the SCOR reference (Supply Chain Council, 2012), from left to right the allocation of a task to the source, make or deliver function of a supply chain. Vertically, the pyramid is split into three levels: the long-term strategic level, the mid-term tactical level and the short-term operational level. The long-term strategic level, supply chain design (SCD), comprises tasks with a scope of one to several years depending on the sector. These tasks typically cover the structural design of the supply chain and the rough process definition (Kuhn and Hellingrath, 2002). However, SCD tasks are not described in detail in the SCM task model. For the mid-term, level, supply chain planning (SCP), the model provides a more detailed description of tasks. SCP contains all planning-related jobs, e.g. a collaborative supply planning (procurement side) or the company-internal production planning. Based on the SCP results, the supply chain is operated on the short-term level, called supply chain operations. Operational decisions have a time horizon of minutes to usually one day and comprise, e.g. orders to refill stocks or transport disposition (Chopra and Meindl, 2010, p. 26; Kuhn and Hellingrath, 2002).

After having introduced supply chain design as a subfield of supply chain management as well as having roughly outlined an existing model for structuring SCM tasks, the following sections focus on structuring SCD tasks. In the subsequent section, the methodology for deriving a classification of SCD tasks based on a textbook review is being described.

2.2. Methodology of Textbook Review

In order to define suitable keywords for the literature review, the first step of the literature review process comprised the identification of corresponding expressions for "supply chain design". Based on the expertise of the authors in research and teaching, 16 textbooks and collected editions on supply chain management were selected, of which half was international and written in English, the other half being of German origin. Patterns and common themes determined to be necessary for supply chain design among the sources were identified. The terminology and boundaries used to describe the subfield of supply chain design was recorded. As a result of the review, apart from supply chain design, the terms supply chain network design, strategic (supply) network design, supply chain configuration, strategic network planning, and network design or configuration are used for describing SCD tasks (see Table 1).

Table 1: Overview of supply chain design terminology used in major SCM books

Original Language ENG	Bogaschewsky et al., 2012	Chandra and Grabis, 2007	Chopra and Meindl, 2010	Cohen and Roussel, 2006	Stadtler and Kilger, 2008	Jung et al., 2007	Simchi-Levi et al., 2009	Watson et al., 2013
SCD term	Strategic Supply Network Design	Supply Chain Configuration	Supply Chain Strategy or Design	Supply Chain Configuration	Strategic Network Design	Supply Chain Design	Supply Chain Design	Supply Chain Network Design
Original Language GER	Arnold et al., 2008	Bretzke, 2008	Gudehus, 2010	Günther, 2005	Kuhn and Hellingrath, 2002	Melzer-Ridinger, 2007	Pfohl, 2010	Schönsleben, 2011
Original term	Supply Chain Design	Netzwerk Design oder Konfiguration	Gestaltung von Lieferketten und -netzwerken	Strategic Network Design	Strategische Netzwerkg-estaltung	Supply Chain Design	Supply Chain Netzwerk-design	Supply Chain Design
SCD term (translated)	Supply Chain Design	Network Design or Configuration	Supply Chain Design	Strategic Network Design	Strategic Network Design	Supply Chain Design	Supply Chain Network Design	Supply Chain Design

After an overview of SCD terms had been generated, the key questions or tasks related to SCD were identified and tabulated. The different sources had been revised to identify subtasks and resolve ambiguities. In an iterative process, subtasks were aggregated under an overarching category. The resulting categories are not entirely independent of each other as most have related issues to other categories. The results of the textbook review are presented in the following section.

2.3. Review Results

The review of major textbooks and collected editions has shown that the tasks of SCD can typically be separated into three main groups: Superordinate SCD tasks, supply chain structure and supply chain process design. The groups and the tasks included therein are described in the following sections.

Superordinate supply chain design tasks

Covering the top level decisions and tasks within SCM, SCD receives objectives from and needs to be aligned to the overall corporate strategy (Cohen and Roussel, 2006, p. 24). In order to achieve the so-called "strategic fit" (Chopra and Meindl, 2010, p. 39), the first major SCD task is to *identify the appropriate SC strategy* (Melzer-Ridinger, 2007, p. 19). A number of different frameworks exist for identifying adequate supply chain strategies dependent on e.g. the product type (e.g. Fisher, 1997, Lee, 2002) or the life cycle stage of products (Chopra and Meindl, 2010, p. 46; Parlings and Klingebiel, 2012). Determining the right SC strategy is a cross-sectional task originating from the superior corporate strategy process and being a relevant input factor for the following SCD tasks. The overall goal is to design and align the supply chain accordingly to the supply chain strategy (Chopra and Meindl, 2010, pp. 37–58).

To achieve a satisfying alignment of the supply chain to the strategy, an accurate measuring of the level of attainment of the overall objectives is necessary. Thus, appropriate indicators need to be defined and arranged in a target system (Parlings et al., 2013). *The definition of a target system* for SCM was identified as being the second superordinate task within SCD.

Supply shain structure design

The second group of tasks is related to the design of the supply chain structure. After the supply chain strategy has been defined and a target system is installed, it is possible to design the network accordingly to these characteristics. Tasks which are named in literature can be divided into five key sections: Make-or-buy decision, supply chain partner selection, facility selection, product and customer allocation, and dimensioning of capacities.

The first task in designing the supply chain structure is to carry out the *make-or-buy decision* (Melzer-Ridinger, 2007, p. 20; Schönsleben, 2011, pp. 70–75). It needs to be decided whether value is created by the company itself or should be sourced from a different party (Cuber et al., 2009, pp. 70 f.). The value can consist of the production of a product or services such as transport or warehousing. If the existing status changes, it is either called "insourcing" or "outsourcing" (Rudolph, 2009, p. 48; Schönsleben, 2011, p. 70). Further SCD tasks are generally considered to be subordinate to the make-or-buy-decision, as this decision determines the required own planning effort and the scope of action for the following design tasks, e.g. suppliers having fixed network locations.

The *selection of supply chain partners* is closely related to make-or-buy decision and is mutually dependent on it. Cooperating companies need to be chosen when the decision on outsourced services or products is made. Regarding the procurement side, *supplier selection* comprises the choice of SC partners (Chopra and Meindl, 2010, pp. 410 ff.). In literature, this part clearly belongs to supply chain design (Chopra and Meindl, 2010, p. 25; Ülkü and Schmidt, 2011; Vanteddu et al., 2011a). Tightly related to the supplier selection is the determination of the sourcing strategy. Different sourcing concepts are to be combined in order to follow a distinct strategy (Arnold et al., 2008b, pp. 271, 280-281). The most important decisions include the choice between single- or multi-sourcing (buying from one or more suppliers) and local or global sourcing (Voigt, 2008, pp. 189–198)}(Arnold et al., 2008b, pp. 280–281). However, the determination and design of the sourcing strategy cannot only referred to SCD as it is rather considered a cross-section task, often to be dealt with in a companies' procurement department (Pauli, 2012, pp. 9, 29 f.).

Decisions affecting *facility selection* include the determination of (Chopra and Meindl, 2010, p. 125; Schönsleben, 2011, p. 96):

1. The role of facilities (What role does each facility play? E.g. production site, warehouse, distribution centre. Which processes are performed at each facility?),
2. The number of facilities of each role (How many facilities are needed for each role?)
3. The location of facilities (Where is the facility located?)

Two consequences result from these aspects: the layers of the network and the vertical range of manufacturing. The latter one defines which value creating processes are performed at each facility or by which supply chain partner (Zäpfel, 2000, p. 132). This decision leads into the *allocation* of products to locations for production or warehousing purposes. The allocation of products to factories deals with determining which facilities are responsible for which value creation process. Beside this production orientated decision, the sourcing allocation problem deals with allocating sourced parts to supply sources or warehousing facilities. In the distribution allocation customers (e.g. retail stores, markets) are assigned to production or warehousing facilities (Chopra and Meindl, 2010, p. 126).

Besides the role and location of facilities such as warehouses and production sites, their *capacities* have a significant impact on the supply chain performance. Therefore, the *dimensioning of capacities* is the third major task in designing the supply chain structure (Chopra and Meindl, 2010, pp. 125–126). However, not only facilities need to be dimensioned with regard to supply chains. In addition, the capacities of processes such as transport relations must be determined (Gudehus, 2010, pp. 125 f.).

The tasks described in this section are carried out for designing the supply chain structure throughout all functions of the supply chains namely source, make and deliver. Therefore, referring to the SCM task model introduced in section 2.1, these tasks are not differentiated horizontally.

Supply chain process design

Based on the created network structure, the rough definition of intra- and inter-company *processes* is realized. This is the third section of SCD tasks. Typical logistic processes especially involve the material and information flow (Pfohl, 2010, pp. 7–10). Rarely, the finance flow is also regarded as being part of logistic processes (Jünemann and Pfohl, 1989, p. 12; Hellingrath and Eberhardt, 2006). The coordination of material and information flow is crucial regarding the success of the supply chain, as the principles "information flow ahead" or "information replaces inventory" (Kuhn and Hellingrath, 2003, p. 653) show.

According to the structure of the task model, the process design tasks can first be distinguished into sourcing processes, production ("make") logistics processes, and distribution ("deliver") processes. This logic is also encouraged by the widespread and international recognised SCOR-recommendation (Supply Chain Council, 2012). *Sourcing process design* includes the decision on long-term inbound logistics concepts within the range of the sourcing strategy. Examples for sourcing processes are the implementation of concepts like "vendor-managed-inventory" (VMI) or delivery concepts such as "just-in-time" (JIT) and "just-in-sequence" (JIS) (Potter et al., 2007; Wilke, 2012, p. 85).

The *design of production logistics processes* in SCM particularly involves the decision on superordinate production concepts. According to SCOR, make-to-stock (MTS), make-to-order (MTO), and engineer-to-order (ETO), can be distinguished on a high aggregation level (Supply Chain Council, 2012). Another typical logistics-related production process design task is the determination of the order penetration point (OPP). This task includes deciding which „processes are part of the push or pull phase of the chain" (Chopra and Meindl, 2010, p. 70).

The third subtask addresses the design of the distribution network processes. Various standard *distribution processes* exist regarding the interdependence of product strategy and the market to be served (Simchi-Levi et al., 2009, pp. 209–241; Chopra and Meindl, 2010, pp. 118 f.). For instance, SCOR provides a set of recommended distribution processes for MTS-, MTO-, and ETO- and retail products. A specific task with regard to the distribution process design is the development of an appropriate inventory policy (Simchi-Levi et al., 2009, pp. 33–48; Chopra and Meindl, 2010, pp. 66 f.). There are various research articles dealing with the topic to develop an algorithm for the optimal determination of such "inventory policies" (Marinda and Garrido, 2009; Klingebiel and Li, 2011).

The design of information and communication processes as well as transport relations are considered as being cross-sectional tasks within the process design section. They affect a supply chain's source, make, and deliver processes. The design of *information and communication processes* is particularly important for SCM, as „information deeply affects every part of the supply chain and impacts every other driver" (Chopra and Meindl, 2010, p. 69) and SCM task. Information and communication processes are instantaneously important for the coordination and cooperation within the supply chain (Simchi-Levi et al., 2009, p. 153; Hegmanns, 2009, pp. 15–21). Therefore, particularly the design of information and communication processes and the selection of appropriate information systems to be used are genuine SCM tasks (Chopra and Meindl, 2010, p. 25). For instance, different information systems are applied in a supply chain depending on the position of the OPP. Regarding push-systems (up-stream part of a supply chain seen from the OPP); MRP-systems are the key information source. Pull-systems have a high need for information concerning the demand (e.g. forecasting, point-of-sale data, etc.) (Chopra and Meindl, 2010, p. 70). Another important decision regarding information and communication processes is to be made according to the degree of centralised and decentralised information exchange. Especially modern technologies facilitate decentralised, direct information exchange among supply chain partners, for instance using agent-systems based on real-time-RFID-data (Uckelmann et al., 2011; Hegmanns et al., 2012). Among others, the ECR-initiative provides various design alternatives for information and communication systems regarding consumer goods, e.g. CPFR (Seifert, 2006).

The *design of transport relations* is closely linked to the design of the procurement, production, and distribution processes. Transport processes connect network locations and therefore need to fit the appropriate processes mentioned above. The determination of the suitable means of transport, which is generally provided on certain relations within the logistic system, is a SCD task (Simchi-Levi et al., 2009, pp. 85–87; Chopra and Meindl, 2010, p. 25; Sackmann, 2012, p. 283). Means of transport can be distinguished by criteria such as capacity, flexibility, or transportation cost (Kummer, 2006, p. 67).

2.4. Intermediate Conclusion

In this chapter, the specific, in literature not always consistently assigned tasks of SCD were discussed and classified. The following tasks were identified as being crucial to SCD:

- Superordinate SCD tasks:
  - Supply chain strategy
  - Definition of the SCM target system
- Supply chain structure design:
  - Make-or-buy-decisions
  - Selection of supply chain partners
  - Facility selection
  - Allocation of products, suppliers, markets
  - Capacity dimension
- Supply chain process design:
  - Sourcing process design
  - Production logistics process design
  - Distribution process design
  - Design of communication and information processes
  - Design of transport relations

With regard to the above described dependencies between the tasks, a rough hierarchy in the order superordinate tasks, supply chain structure and supply chain process design can be realised. However, due to the appearing interdependencies among the single tasks in each group, it seems not reasonable to assign them to a superior or inferior role within each group.
Figure 2 summarises this chapter's findings by appropriately arranging the identified SCD tasks. The tasks are arranged in this specific way in order to represent a contribution for filling the remaining "black box" of the above mentioned SCM task model (Kuhn and Hellingrath, 2002). After having developed the "SCD task model" the following chapter describes a first application in a state-of-the art literature review. Based on a journal review, contemporary research in the field of SCD is classified using the SCD task model.

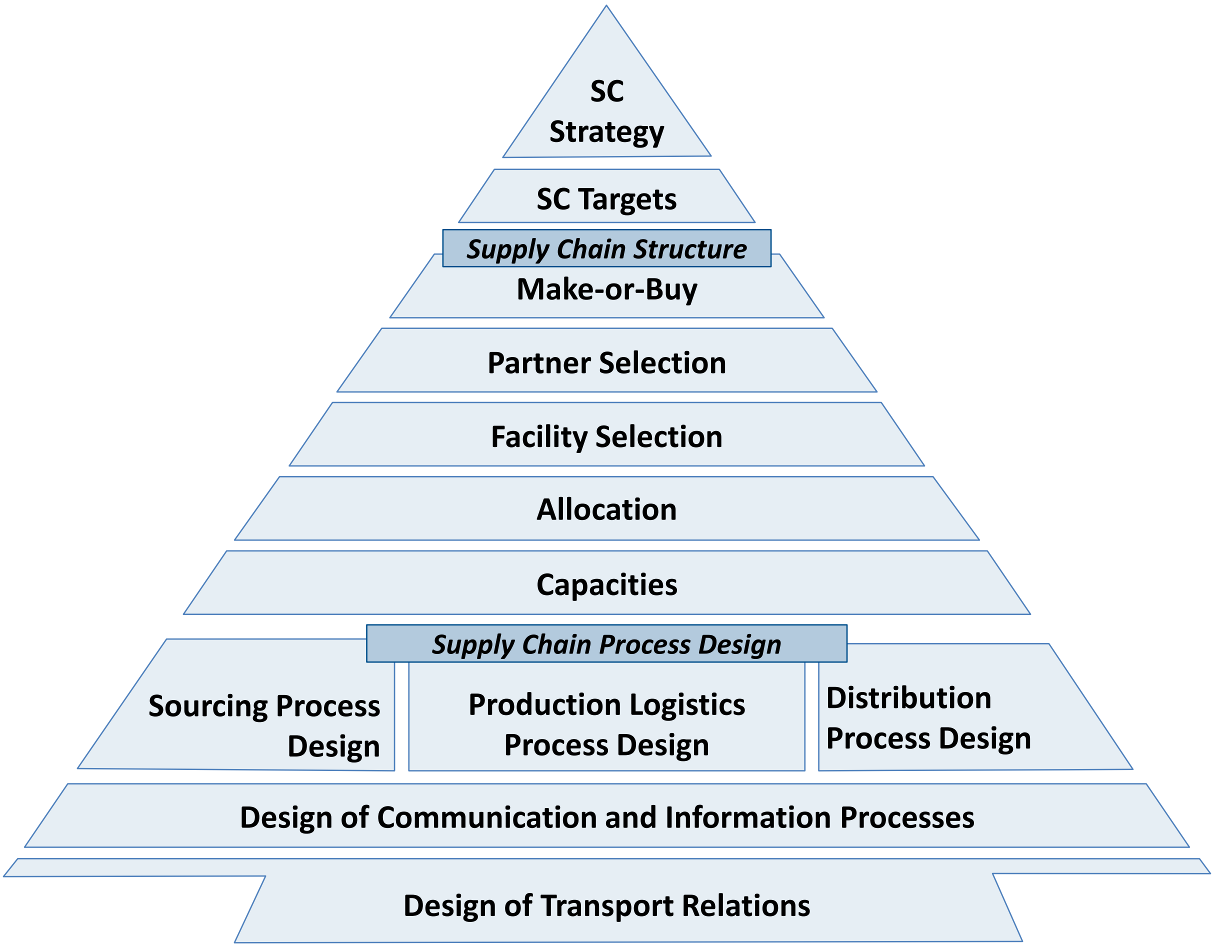

Figure 2: SCD task model

3. Classification of contemporary research in SCD

After a common understanding of SCD has been generated and its main tasks have been classified by extending the SCM task model, this chapter seeks to analyse contemporary research in SCD. For this purpose, a structured literature review on high-ranked journal publications has been carried out. The methodological approach is described in the first section. In the second section, SCD tasks that covered by recent research are being classified using the SCD task model.

3.1. Methodology of the Journal Review

With the more specific and clear understanding of various tasks and decisions necessary at the supply chain design stage of SCM, a systematic review of contemporary research literature in SCD was undertaken. In order to achieve an overview of recent top-level research findings in SCD, high-ranked SCM and logistics journals (top two tiers of multiple ranking systems) have been searched for SCD articles within the past 5 years (January 2008 to May 2013). To validate and contextualize the task framework identified in the textbook review, the various SCD tasks discussed in the article were cross-referenced with the framework tasks.

In order to identify an appropriate methodology for the in-depth literature review, a brief review of previous literature review articles in the field has been carried out. The findings indicated that most studies implemented a systematic review employing content analysis of whatever facet they were interested in (Croom et al., 2000; Seuring and Müller, 2008; Seuring and Gold, 2012; Ghadge et al., 2012). Given the clearly defined scope of the review, it was decided to search within a set of field-specific journals whose quality was externally verified, and then assume that the contained articles were on the average demonstrative of the quality of the journal. The list of journals, in order to maintain quality and relevance of the sources, was compiled from combining the relevant Operations Management, Operations Research, and Supply Chain Management journals from the top two tiers of the ABS journal rankings (grade 4 and grade 3) and the University of Sydney's Transport Logistics and Supply Chain Management journal rankings (tier 4 and tier 3). Table 2 shows the full list of the journals included in the review and their individual rank in each ranking system.

Table 2: List of Journals included in the review

Journal	ABS Journal Ranking 1-4	University of Sydney Journal Ranking Tier 1 - Tier 4
International Journal of Logistics Management	2	Tier 3
International Journal of Logistics: Research and Applications	3	Tier 3
International Journal of Physical Distribution and Logistics Management	2	Tier 3
International Journal of Production Economics	3	Tier 2
Journal of Operations Management	1	Tier 4
Journal of the Operational Research Society	3	Tier 3
Management Science	4	Tier 4
Production and Operations Management	3	Tier 3
Production and Operations Management	3	Tier 3
Supply Chain Management: An International Journal	3	Tier 2
Transportation Research Part A: Policy and Practice	3	Tier 4
Transportation Research Part B: Methodological	4	Tier 4
Transportation Science	3	Tier 3

A structured keyword search was performed, searching for SCD and its most relevant synonyms as identified in the preceding chapter. The search keywords were supply chain design, supply chain configuration and supply chain network design. The keyword search included the publication title and the publication keywords, ensuring the relevance of results. The composite search returned forty-five articles which were read and analysed to extract the various SCD tasks discussed as necessary for the design of a supply chain, and to note the central problem of focus the research was addressing. The findings of this review are discussed in detail in the following section.

3.2. Classifying contemporary research with the SCD task model

The search returned 45 relevant articles that address supply chain design or its synonyms in their title or keyword. The full list of the articles and the tasks covered in each article is displayed in the summative Table 3. The following general results with regard to the relevance of the SCD task model introduced in this paper can in a first step be derived: Every article does at least cover one of the classified in the SCD task model. Vice versa, every SCD task identified in this paper has been covered in those highly ranked contemporary journal papers. This emphasises the relevance of the tasks to SCD and indicates that those tasks are still subject to current research.

Table 3: Review of contemporary journal articles on Supply Chain Design

SC Task / Authors	SC Strategy	SC Targets	Make-or-buy	Partner Selection	Facility selection	Allocation	Capacities	Sourcing process	Production locistics process	Distribution process	Inform. & Commun. Process	Transport relations	Others: e.g. Risk, Robustness
Akanle and Zhang, 2008				X		X		X	X	X		X	X
Amini and Li, 2011					X				X	X			X
Azaron, 2008		X			X	X							X
Baghalian et al., 2013					X		X		X	X			X
Baumgartner et al., 2012					X					X		X	
Bidhandi et al., 2009					X	X	X						
Bogataj et al., 2011					X								
Caniato et al., 2011	X												
Cheng, 2011	X	X	X				X				X		
Chou et al., 2010				X		X	X						X
Frota Neto et al., 2008	X	X							X			X	
Gobbi, 2011	X							X		X			
Hammami et al . 2008					X	X	X					X	
Hammami et al., 2009				X	X	X	X	X	X	X			
Henkow and Norrman, 2011				X	X							X	
Hsu and Li, 2009					X	X	X						X
Hsu and Li, 2011						X	X						X
Huang and Qu, 2008				X									
Hussain, 2012									X	X	X		
Klibi et al., 2010				X	X							X	X
Kovács et al., 2010	X			X									
Lee and Wilhelm, 2010		X			X		X	X		X			
Li and Womer, 2012			X	X		X	X	X					
Lien et al., 2011					X			X		X			X
Lin and Wang, 2011	X			X				X	X	X			X
Moncayo-Martinez and Zhang, 2011				X		X						X	
Nagurney, 2010					X		X			X			
Nepal et al., 2011				X	X				X				
Ozsen et al., 2009					X					X	X		
Pero et al., 2010				X	X			X		X			
Qu et al., 2010				X							X		
Schütz et al., 2009					X		X						X
Seuring, 2009	X												
Shukla et al., 2011		X											X
Smith et al., 2009					X								
Sourirajan et al., 2009					X					X			
Sung and Yang, 2008					X					X		X	
Thanh et al., 2008				X	X		X		X	X			
Tiwari et al., 2010					X	X				X		X	
Tsao et al., 2012					X	X				X			
Ülkü and Schmidt, 2011	X		X	X									
Vanteddu et al., 2011		X		X									
Walther et al., 2012					X	X	X						
Wu et al., 2008	X									X			
Yao et al., 2010					X	X				X			
Cum. Coverage	9	6	3	16	26	14	14	8	9	20	4	9	12

Remarkably few articles cover the field of SCD in width respectively covering at least a group of tasks. One example for a paper covering a group of SCD tasks is the contribution by Hammami et al. (2009). The authors introduce a strategic-tactical model for SCD in the delocalisation context. However, most of the journal papers included in the review tend to focus on a specific problem, introducing a new algorithm or a specific case study. This is not surprising since journal papers usually do not cover broad topics such as SCD holistically but rather concentrate on solving individual problems. Among the SCD specific problems covered in the journal articles, facility selection seems to attract the highest attention. More than half of the papers (26) included in the review cover the topic of facility location. This topic seems to be popular among operations research and operations management researchers since especially facility location provides a high challenge for optimisation models (e.g. Nagurney, 2010; Baumgartner et al., 2012).

Noticeably many papers handling with facility selection do also cover distribution process design (15). This emphasises the consumer-driven view to supply chain management especially shaped by American researchers. Facility location problems in SCM do often focus on facilities downstream from production sites (e.g. production warehouses, central warehouses, regional warehouses) and are complemented by the design of corresponding (distribution) processes. Besides facility selection and distribution process design, partner selection as well as solving allocation and capacity problems are most frequently dealt with in the journal papers reviewed. All in all, recent SCD research seems to focus on improving methods and optimisation models for supply chain structure tasks. Figure 3 summarises the findings by indicating the coverage of SCD tasks in the reviewed journal articles. The circles attached to each tasks include the number of articles covering the corresponding task among the sample size of 45.

In addition to the tasks that could obviously be matched to the task model, several additional tasks were focused in some papers. Remarkably many articles focus on risk management (e.g. Chou et al., 2010; Lien et al., 2011), dealing with uncertainty (e.g. Azaron et al., 2008; Lin and Wang, 2011), and designing of robust supply chains (e.g. Klibi et al., 2010; Baghalian et al., 2013). The high relevance of those tasks to SCD might be due to the increasing impact of recent trends such as climate change, terror attacks and turmoil in some parts of the world as well as shortening product life cycles on globalised supply chains. With regard to the task model introduced in this paper, those topics should be classified in the superordinate SCD tasks since the strategy and targets of supply chains need to be adapted in order to handle those challenges. However, the extension or adaption of the SCD task model remains open to future discussions.

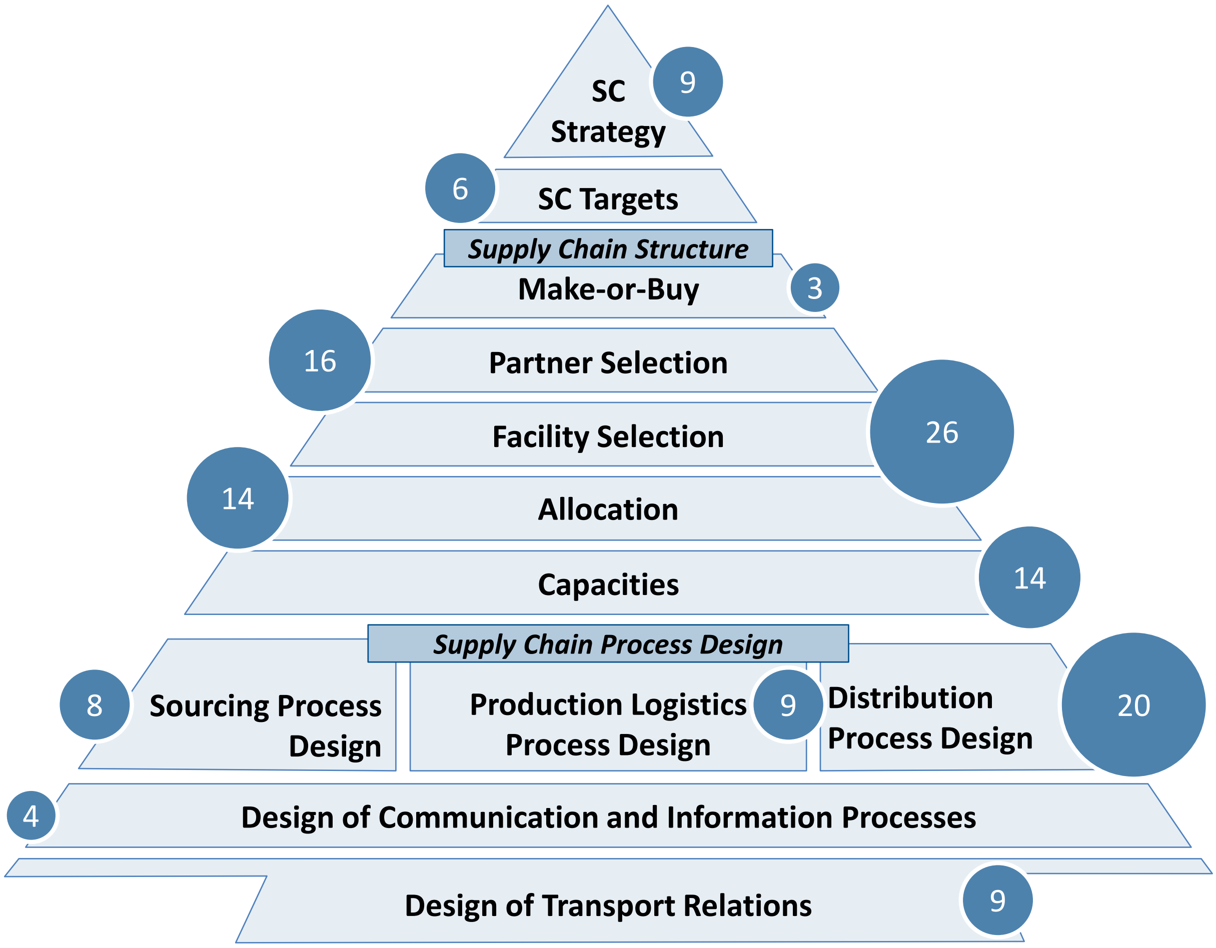

Figure 3: Coverage of supply chain design tasks in 45 reviewed journal papers

4. Conclusion and outlook

In this paper, an approach for classifying SCD tasks has been developed and validated based on a two-stage literature review. The discussion of SCD as the subfield of SCM, that integrates long-term and strategic decisions on the configuration, planning, and management of supply chains has revealed that a consistent definition and a structured characterisation of its tasks are still missing. Consequently, a coherent understanding of SCD in research as well practice is missing. For designing supply chains in practice this leads to a non-coordinated and independent execution of the various tasks carried out when designing supply chains.

To respond to this problem, a review of relevant textbooks covering this topic has been carried out. The terminology in the context of SCD has been analysed and corresponding tasks have been identified. The findings have been summarised by extending an already existent SCM task model (Kuhn and Hellingrath, 2002, p. 143) by a specified description and classification of supply chain design tasks. This extension is referred to as the "SCD task model". The findings have then been validated by carrying out an in-depth literature review of contemporary high-ranked journal articles dealing with SCD. The applicability of the task model has thereby been demonstrated: Every article did at least cover one SCD task and every task indicated in the model was covered by recent research. Furthermore, the result of this review has pointed out that facility selection and distribution process design are the tasks that have been addressed most frequently in recent research published in major logistics and SCM related journals.

The findings presented in this paper do contribute to both research as well as practice. With regard to research, the findings contribute to further delineating SCD as a subfield of SCM by clearly pointing out the major tasks. As has been demonstrated in section 3.2, the SCD task model is a useful framework for classifying research in the field of SCD. Furthermore, in combination with the already existent SCM task model, a holistic framework for classifying and describing SCM tasks on all managerial levels from long-term strategic tasks through mid-term tactical tasks to short-term operational tasks is available. With regard to practice, the findings can be a useful basis for the development of tools for SCD. Companies developing SCD tools can use the task model for pointing out the tasks covered by their tool. Furthermore, an improvement of the understanding of SCD and its tasks can lead to a more efficient organisational structure and alignment of the various departments involved in carrying out SCD tasks.

Although the task model presented in this contribution is based on an in-depth review of relevant textbooks and has been validated by a review of contemporary journal papers, the findings should be seen as a first step in classifying SCD tasks. Empirical studies might help to further approve the task model. Furthermore, the task model can be useful for carrying out a structured review of the state-of-the art of tools available for different tasks in SCD. In addition, the classification does provide a basis for further analysing the individual tasks in detail. In order to develop powerful SCD software tools, it is important to analyse the input data needs for each SCD task. Tasks with similar input data and optimisation methods can then be combined and solved by an appropriate tool.

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6. References

Akanle, O. and Zhang, D. (2008). Agent-based model for optimising supply-chain configurations, *International Journal of Production Economics,* Vol. 115 No. 2, pp. 444–460.

Amini, M. and Li, H. (2011). Supply chain configuration for diffusion of new products: An integrated optimization approach, *Omega*, Vol. 39 No. 3, pp. 313–322.

Arnold, D., Furmans, K., Isermann, H., Kuhn, A. and Tempelmeier, H. (Eds.) (2008a). *Handbuch Logistik,* 3rd ed., Springer, Berlin, Heidelberg.

Arnold, D., Furmans, K., Isermann, H., Kuhn, A. and Tempelmeier, H. (Eds.) (2008b). *Handbuch Logistik,* 3rd ed., Springer, Berlin, Heidelberg.

Azaron, A., Brown, K., Tarim, S. and Modarres, M. (2008). A multi-objective stochastic programming approach for supply chain design considering risk, *International Journal of Production Economics*, Vol. 116 No. 1, pp. 129–138.

Baghalian, A., Rezapour, S. and Farahani, R.Z. (2013). Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case, *European Journal of Operational Research*, Vol. 227 No. 1, pp. 199–215.

Baumgartner, K., Fuetterer, A. and Thonemann, U.W. (2012). Supply chain design considering economies of scale and transport frequencies, *European Journal of Operational Research*, Vol. 218 No. 3, pp. 789–800.

Bertsch, S. and Nyhuis, P. (2011). Wandlungsfähige Produktionslogistik. Neue Forderungen an das Logistik-Controlling, *ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 106 No. 9, pp. 630–635.

Bogaschewsky, R., Eßig, M., Lasch, R. and Stölzle, W. (Eds.) (2012). *Supply Management Research: Aktuelle Forschungsergebnisse 2012*, Springer Gabler, Wiesbaden.

Bogataj, M., Grubbström, R.W. and Bogataj, L. (2011). Efficient location of industrial activity cells in a global supply chain, *International Journal of Production Economics*, Vol. 133 No. 1, pp. 243–250.

Bretzke, W.-R. (2008). *Logistische Netzwerke*, Springer, Berlin.

Caniato, F., Caridi, M., Castelli, C. and Golini, R. (2011). Supply chain management in the luxury industry: A first classification of companies and their strategies, *International Journal of Production Economics*, Vol. 133 No. 2, pp. 622–633.

Chandra, C. and Grabis, J. (2007). *Supply chain configuration: Concepts, solutions and applications*, Springer, New York.

Cheng, L.-C. (2011). Assessing performance of utilizing organizational modularity to manage supply chains: Evidence in the US manufacturing sector, *International Journal of Production Economics*, Vol. 131 No. 2, pp. 736–746.

Chopra, S. and Meindl, P. (2010). *Supply Chain Management: Strategy, Planning, and Operation*, Pearson Education, Upper Saddle River, New Jersey.

Chou, Y.-C., Huang, H.-Y., Jahn, J. and Kuo, C.-H. (2010). A framework of economic analysis for tapered technology-manufacturing alliances, *International Journal of Production Economics*, Vol. 127 No. 2, pp. 249–261.

Christopher, M. (2005). *Logistics and Supply Chain Management: Creating value-added networks*, Pearson Education, Harlow.

Cirullies, J., Klingebiel, K. and Scavarda, L.F. (2012). A Conceptual Framework for Green Supply Chain Design, paper presented at The XVIII international conference on Industrial Engineering and Operations Management, 9.-11.7.2012, Guimarães, Portugal.

Cohen, S. and Roussel, J. (2006). *Strategisches Supply Chain Management*, Springer, Berlin, Heidelberg.

Croom, S., Romano, P. and Giannakis, M. (2000). Supply chain management: an analytical framework for critical literature review, *European Journal of Purchasing & Supply Management*, Vol. 6 No. 1, pp. 67–83.

Cuber, S., Helmig, J., Quick, J. and Wienholdt, H. (2009). Supply Chain Design. Methoden zur Gestaltung und Optimierung von Wertschöpfungsketten, *UdZ - Unternehmen der Zukunft*, Vol. 9 No. 1, pp. 69–71.

Fisher, M.L. (1997). What is the Right Supply Chain for Your Product? A simple framework can help you figure out the answer., *Harvard Business Review* März-April, pp. 105–116.

Frota Neto, J.Q., Bloemhof-Ruwaard, J., van Nunen, J. and van Heck, E. (2008). Designing and evaluating sustainable logistics networks, *International Journal of Production Economics*, Vol. 111 No. 2, pp. 195–208.

Ghadge, A., Dani, S. and Kalawski, R. (2012). Supply chain risk management: present and future scope, *International Journal of Logistics Management, The*, Vol. 23 No. 3, pp. 313–339.

Gobbi, C. (2011). Designing the reverse supply chain: the impact of the product residual value, *International Journal of Physical Distribution & Logistics Management*, Vol. 41 No. 8, pp. 768–796.

Gudehus, T. (2010). *Logistik: Grundlagen - Strategien - Anwendungen*, Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg.

Günther, H.-O. (2005). *Supply Chain Management und Logistik: Optimierung, Simulation, Decision Support ; mit 84 Tabellen, SpringerLink: Springer e-Books*, Physica-Verl., Heidelberg.

Hammami, R., Frein, Y. and Hadj-Alouane, A.B. (2008). Supply chain design in the delocalization context: Relevant features and new modeling tendencies, *International Journal of Production Economics*, Vol. 113 No. 2, pp. 641–656.

Hammami, R., Frein, Y. and Hadj-Alouane, A.B. (2009). A strategic-tactical model for the supply chain design in the delocalization context: Mathematical formulation and a case study, *International Journal of Production Economics*, Vol. 122 No. 1, pp. 351–365.

Hegmanns, T. (2009). *Dezentrales Planungs- und Prozesskonzept für ein kollaboratives Bedarfs- und Kapazitätsmanagement in Produktionsnetzwerken, Unternehmenslogistik*, Verl. Praxiswissen, Dortmund.

Hegmanns, T., Parlings, M. and Winkler, M. (2012). Dezentrale Informationssysteme für das Supply Chain Event Management. In Müller, E. and Bullinger, A.C. (eds.), *Intelligent vernetzte Arbeits- und Fabriksysteme, Chemnitz, 08.-09.11.2012*, Institut für Print- und Medientechnik der TU Chemnitz, Chemnitz, pp. 97–106.

Hellingrath, B. and Eberhardt, S.M. (2006). Werkzeuge für das Supply Chain Design. In ten Hompel, M. (ed.), *Software in der Logistik: Marktspiegel*, *Logistik Praxis*, 1st ed., Huss, München, pp. 94–97.

Henkow, O. and Norrman, A. (2011). Tax aligned global supply chains: Environmental impact illustrations, legal reflections and crossfunctional flow charts, *International Journal of Physical Distribution & Logistics Management*, Vol. 41 No. 9, pp. 878–895.

Hsu, C.-I. and Li, H.-C. (2009). An integrated plant capacity and production planning model for high-tech manufacturing firms with economies of scale, *International Journal of Production Economics*, Vol. 118 No. 2, pp. 486–500.

Hsu, C.-I. and Li, H.-C. (2011). Reliability evaluation and adjustment of supply chain network design with demand fluctuations, *International Journal of Production Economics*, Vol. 132 No. 1, pp. 131–145.

Huang, G.Q. and Qu, T. (2008). Extending analytical target cascading for optimal configuration of supply chains with alternative autonomous suppliers, *International Journal of Production Economics*, Vol. 115 No. 1, pp. 39–54.

Hussain, M. (2012). Quantifying the impact of a supply chain's design parameters on the bullwhip effect using simulation and Taguchi design of experiments, *International Journal of Physical Distribution & Logistics Management*, Vol. 42 No. 10, pp. 947–968.

Jünemann, R. and Pfohl, H.-C. (1989). *Materialfluß und Logistik: Systemtechnische Grundlagen mit Praxisbeispielen, Logistik in Industrie, Handel und Dienstleistungen*, Springer, Berlin, Heidelberg, New York.

Jung, H., Chen, F.F. and Jeong, B. (Eds.) (2007). *Trends in Supply Chain Design and Management: Technologies and Methodologies*, Springer, London.

Keßler, S., Schmidt, A. and Wagenitz, A. (2010). *Intelligente Logistik in großen Netzen: Überischt über die Forschungsleistungen des SFB 559 "Modellierung großer Netze in der Logistik"*.

Klibi, W., Martel, A. and Guitouni, A. (2010). The design of robust value-creating supply chain networks: A critical review, *European Journal of Operational Research*, Vol. 203 No. 2, pp. 283–293.

Klingebiel, K., Kuhn, A. and Li, C. Planning Changeability in Distribution Systems. In Delfmann, W. and Wimmer, T. (eds.), *Coordinated autonomous systems: Wissenschaft und Praxis im Dialog, Hamburg*, DVV Media Group, pp. 276–292.

Klingebiel, K. and Li, C. (2011). Optimized Multi-Echelon Inventory Policies In Robust Distribution Networks, paper presented at 25th European Conference on Modelling and Simulation, 07.06.-10.06., Krakow, Poland.

Klingebiel, K. and Li, C. (2012). An integrated approach to robust multi-echelon inventory policy decision. In Byrski, A. (ed.), *Advances in intelligent modelling and simulation: Simulation tools and applications*, *Studies in Computational Intelligence*, Springer, Berlin, Heidelberg, pp. 165–197.

Kovacs, G., Matopoulos, A. and Hayes, O. (2010). A community-based approach to supply chain design, *International Journal of Logistics Research and Applicationsn*, Vol. 13 No. 5, pp. 411–422.

Kuhn, A. and Hellingrath, B. (2002). *Supply Chain Management: Optimierte Zusammenarbeit in der Wertschöpfungskette, Engineering*, Springer, Berlin.

Kuhn, A. and Hellingrath, B. (2003). Auftragsmanagement in Netzwerken. Supply Chain Management. In Warnecke, H.-J., Westkämper, E. and Bullinger, H.-J. (eds.), *Neue Organisationsformen im Unternehmen: Ein Handbuch für das moderne Management*, 2nd ed., Springer, Berlin, Heidelberg, pp. 644–670.

Kummer, S. (2006). *Einführung in die Verkehrswirtschaft*, Facultas, Wien.

Lee, C. and Wilhelm, W. (2010). On integrating theories of international economics in the strategic planning of global supply chains and facility location, *International Journal of Production Economics*, Vol. 124 No. 1, pp. 225–240.

Lee, H., Padmanabhan, V. and Whang, S. (1997). The Bullwhip Effect in Supply Chains, *Sloan Management Review*, Vol. 38 No. 3, pp. 93–102.

Lee, H.L. (2002). Aligning Supply Chain Strategies with Product Uncertainties, *California Management Review*, Vol. 44 No. 3, pp. 105–118.

Li, H. and Womer, K. (2012). Optimizing the supply chain configuration for make-to-order manufacturing, *European Journal of Operational Research*, Vol. 221 No. 1, pp. 118–128.

Lien, R.W., Iravani, S.M.R., Smilowitz, K. and Tzur, M. (2011). An Efficient and Robust Design for Transshipment Networks, *Production and Operations Management*, Vol. 20 No. 5, pp. 699–713.

Lin, C.-C. and Wang, T.-H. (2011). Build-to-order supply chain network design under supply and demand uncertainties, *Transportation Research Part B: Methodological*, Vol. 45 No. 8, pp. 1162–1176.

Marinda, P.A. and Garrido, R.A. (2009). Inventory service-level optimization within distribution network design problem, *International Journal of Production Economics*, Vol. 122 No. 1, pp. 276–285.

Melzer-Ridinger, R. (2007). *Supply Chain Management: Prozess und unternehmensübergreifendes Management von Qualität, Kosten und Liefertreue*, Oldenbourg, München.

Meyr, H., Wagner, M. and Rohde, J. (2002). Structure of advanced planning systems. In Stadtler, H. and Kilger, C. (eds.), *Supply Chain Management and Advanced Planning: Concepts, Model, Software and Case Studies*, Springer, Berlin, pp. 99–104.

Mohammadi Bidhandi, H., Mohd. Yusuff, R., Megat Ahmad,Megat Mohamad Hamdan and Abu Bakar, M.R. (2009). Development of a new approach for deterministic supply chain network design, *European Journal of Operational Research*, Vol. 198 No. 1, pp. 121–128.

Moncayo-Martínez, L.A. and Zhang, D.Z. (2011). Multi-objective ant colony optimisation: A meta-heuristic approach to supply chain design, *International Journal of Production Economics*, Vol. 131 No. 1, pp. 407–420.

Nagurney, A. (2010). Optimal supply chain network design and redesign at minimal total cost and with demand satisfaction, *International Journal of Production Economics*, Vol. 128 No. 1, pp. 200–208.

Nepal, B., Monplaisir, L. and Famuyiwa, O. (2012). Matching product architecture with supply chain design, *European Journal of Operational Research*, Vol. 216 No. 2, pp. 312–325.

Ozsen, L., Daskin, M.S. and Coullard, C.R. (2009). Facility Location Modeling and Inventory Management with Multisourcing, *Transportation Science*, Vol. 43 No. 4, pp. 455–472.

Parlings, M. and Klingebiel, K. (2012). Mastering innovation life cycles from a supply chain perspective. A framework for aligning supply chains along the maturity of technology life cycles, paper presented at The 16th Cambridge International Manufacturing Symposium, 20.-21.09., Cambridge, UK.

Parlings, M., Klingebiel, K. and Cirullies, J. (2013). Determining phase transitions for aligning the supply chain strategy along early life cycle phases of product innovations, paper presented at EurOMA, 07.-12.06.2013, Dublin.

Pauli, M. (2012). *Logistische Lieferantenentwicklung in der Automobilindustrie: Methodische Verbesserung der logistischen Leistungsfähigkeit von Lieferanten bei variantenreicher Serienproduktion, Unternehmenslogistik*, Verl. Praxiswissen, Dortmund.

Pero, M., Rossi, T., Noé, C. and Sianesi, A. (2010). An exploratory study of the relation between supply chain topological features and supply chain performance, *International Journal of Production Economics*, Vol. 123 No. 2, pp. 266–278.

Pfohl, H.-C. (2010). *Logistiksysteme: Betriebswirtschaftliche Grundlagen,* 8th ed., Springer, Berlin, Heidelberg.

Plümer, T. (2003). *Logistik und Produktion, Managementwissen für Studium und Praxis*, Oldenbourg, München.

Potter, A., Towill, D. and Disney, S.M. (2007). Integration Transport into Supply Chains. Vendor Managed Inventory (VMI). In Jung, H., Chen, F.F. and Jeong, B. (eds.), *Trends in Supply Chain Design and Management: Technologies and Methodologies*, Springer, London, pp. 331–344.

Qu, T., Huang, G.Q., Zhang, Y. and Dai, Q. (2010). A generic analytical target cascading optimization system for decentralized supply chain configuration over supply chain grid, *International Journal of Production Economics*, Vol. 127 No. 2, pp. 262–277.

Rudolph, T. (2009). *Strategien von Logistikdienstleistern im Kontraktlogistikmarkt: Eine fallstudienbasierte Analyse der Strategien ausgewählter internationaler Unternehmen der Kontraktlogistik vor dem Hintergrund aktueller Empfehlungen der strategischen Managementliteratur, Schriftenreihe Logistik-Management in Forschung und Praxis*, Vol. 25, Kovač, Hamburg.

Sackmann, D. (2012). Intermodale Transportkettenplanung in logistischen Netzwerken. In Bogaschewsky, R., Eßig, M., Lasch, R. and Stölzle, W. (eds.), *Supply Management Research: Aktuelle Forschungsergebnisse 2012*, Springer Gabler, Wiesbaden, pp. 281–291.

Schönsleben, P. (Ed.) (2011). *Integrales Logistikmanagement: Operations und Supply Chain Management innerhalb des Unternehmens und unternehmensübergreifend,* 6th ed., Springer, Berlin, Heidelberg.

Schütz, P., Tomasgard, A. and Ahmed, S. (2009). Supply chain design under uncertainty using sample average approximation and dual decomposition, *European Journal of Operational Research*, Vol. 199 No. 2, pp. 409–419.

Seifert, D. (2006). Efficient Consumer Response. In Zerres, M.P. and Zerres, C. (eds.), *Handbuch Marketing-Controlling,* Springer, Berlin, pp. 375–394.

Seuring, S. (2009). The product-relationship-matrix as framework for strategic supply chain design based on operations theory, *International Journal of Production Economics*, Vol. 120 No. 1, pp. 221–232.
Seuring, S. and Gold, S. (2012). Conducting content-analysis based literature reviews in supply chain management, *Supply Chain Management: An International Journal*, Vol. 17 No. 5, pp. 544–555.
Seuring, S. and Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management, *Journal of Cleaner Production*, Vol. 16 No. 15, pp. 1699–1710.
Shukla, A., Lalit, V.A. and Venkatasubramanian, V. (2011). Optimizing efficiency-robustness trade-offs in supply chain design under uncertainty due to disruptions, *International Journal of Physical Distribution & Logistics Management*, Vol. 41 No. 6, pp. 623–647.
Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2009). *Designing and Managing the Supply Chain: Concepts, Strategies and Case studies*, 3rd ed., McGraw-Hill, Boston, Mass.
Smith, H.K., Laporte, G. and Harper, P.R. (2009). Locational analysis: highlights of growth to maturity, *Journal of the Operational Research Society*, Vol. 60, pp. S140.
Sourirajan, K., Ozsen, L. and Uzsoy, R. (2009). A genetic algorithm for a single product network design model with lead time and safety stock considerations, *European Journal of Operational Research*, Vol. 197 No. 2, pp. 599–608.
Stadtler, H. (2002). Basics of supply chain management. In Stadtler, H. and Kilger, C. (eds.), *Supply Chain Management and Advanced Planning: Concepts, Model, Software and Case Studies*, Springer, Berlin, pp. 7–28.
Stadtler, H. and Kilger, C. (Eds.) (2008). *Supply chain management and advanced planning: Concepts, models, software, and case studies*, 4th ed., Springer, Berlin.
Sung, C.S. and Yang, W. (2006). An exact algorithm for a cross-docking supply chain network design problem, *Journal of the Operational Research Society*, Vol. 59 No. 1, pp. 119–136.
Supply Chain Council (2012). *SCOR 11.0 Model Reference*.
ten Hompel, M. and Hellingrath, B. (2007). IT & Forecasting in der Supply Chain. In Wimmer, T. and Bobel, T. (eds.), *Effizienz - Verantwortung -Erfolg, Berlin, 17. - 19. Oktober 2007*, Dt. Verkehrs-Verl., Hamburg, pp. 281–310.
Thanh, P.N., Bostel, N. and Péton, O. (2008). A dynamic model for facility location in the design of complex supply chains, *International Journal of Production Economics*, Vol. 113 No. 2, pp. 678–693.
Tiwari, M., Raghavendra, N., Agrawal, S. and Goyal, S. (2010). A Hybrid Taguchi–Immune approach to optimize an integrated supply chain design problem with multiple shipping, *European Journal of Operational Research*, Vol. 203 No. 1, pp. 95–106.
Tsao, Y.-C., Mangotra, D., Lu, J.-C. and Dong, M. (2012). A continuous approximation approach for the integrated facility-inventory allocation problem, *European Journal of Operational Research*, Vol. 222 No. 2, pp. 216–228.
Uckelmann, D., Harrison, M. and Michahelles, F. (2011). *Architecting the internet of things*, Springer, Berlin, Heidelberg, New York.
Ülkü, S. and Schmidt, G.M. (2011). Matching Product Architecture and Supply Chain Configuration, *Production and Operations Management*, Vol. 20 No. 1, pp. 16–31.
Vanteddu, G., Chinnam, R.B. and Gushikin, O. (2011a). Supply chain focus dependent supplier selection problem, *International Journal of Production Economics*, Vol. 129 No. 1, pp. 204–216.

Vanteddu, G., Chinnam, R.B. and Gushikin, O. (2011b). Supply chain focus dependent supplier selection problem, *International Journal of Production Economics*, Vol. 129 No. 1, pp. 204–216.

Voigt, K.-I. (2008). *Industrielles Management: Industriebetriebslehre aus prozessorientierter Sicht*, Springer, Berlin, Heidelberg.

Walther, G., Schatka, A. and Spengler, T.S. (2012). Design of regional production networks for second generation synthetic bio-fuel – A case study in Northern Germany, *European Journal of Operational Research*, Vol. 218 No. 1, pp. 280–292.

Watson, M., Lewis, S., Cacioppi, P. and Jayaraman, J. (2013). *Supply chain network design: Applying optimization and analytics to the global supply chain*, FT Press, Upper Saddle River, N.J.

Wilke, J. (2012). *Supply Chain Koordination durch Lieferverträge mit rollierender Mengenflexibilität: Eine Simulationsstudie am Beispiel von Lieferketten der deutschen Automobilindustrie*, Gabler, Wiesbaden.

Wu, T., Wang, W., Tang, C.S., Lui, D., Gao, F. and Fang, C. (2008). How do foreign cosmetics companies align their supply chains and distribution channels in China?, *International Journal of Logistics: Research and Applications*, Vol. 11 No. 3, pp. 201–228.

Yao, Z., Lee, L.H., Jaruphongsa, W., Tan, V. and Hui, C.F. (2010). Multi-source facility location–allocation and inventory problem, *European Journal of Operational Research*, Vol. 207 No. 2, pp. 750–762.

Zäpfel, G. (2000). *Strategisches Produktions-Management, Internationale Standardlehrbücher der Wirtschafts- und Sozialwissenschaften,* 2nd ed., Oldenbourg, München.

A network theory approach for robustness measurement in dynamic manufacturing systems

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Abstract
Robustness is a key characteristic of manufacturing systems that are embedded in highly fluctuating environments. These fluctuations are caused by short-term demand changes, changing customer requirements, or disruptions in the supply chain, such as delivery delays or material shortages. In order for a company to stay competitive and profitable, the performance of a manufacturing system should not significantly deviate in the face of such fluctuations, i.e. the manufacturing system should display a robust performance. Therefore, different approaches to measure and implement robustness in manufacturing systems have been proposed (Telmoudi et al. 2008; Feng 2009). In this paper we present a new approach on how to assess manufacturing system robustness using graph-theoretical network measures. We further analyze the quality of a specific robustness network measure under dynamic conditions (i.e. changing customer demand).

Keywords: **robustness, network measures, manufacturing, job-shop**

1. Introduction

As complexity in manufacturing systems rises (increasing variety of machines, higher amount of process steps due to more sophisticated products), failures such as machine errors or material shortages are more likely to propagate through the network of machines or work stations in a manufacturing system. This can lead to under-utilization, due date delays or quality defects, i.e. a decrease in overall performance. Robustness, which in general can be described as a system characteristic which "enables the system to maintain its functionalities against external and internal perturbations" (Kitano 2004), thus seems a desirable system characteristic for a manufacturing system on the system level. Various approaches exist to incorporate robustness in different aspects of manufacturing, e.g., robust production control, robust production planning & scheduling or robust capacity design (Tolio et al. 2011; Goren & Sabuncuoglu 2009; Toonen et al. 2012).

In complex network science, graph-theoretical network measures have proven to be a suitable tool to analyze the characteristics of different types of natural or man-made networks (Albert & Barabási 2002; Boccaletti et al. 2006). One of the many network characteristics that researchers in this field have focused on in the past is network robustness (Barabási 1999; Callaway et al. 2000; Jeong et al. 2000). It has recently been suggested to apply such network measures to classical manufacturing problems, such as machine grouping (Vrabič et al. 2012), since the network of machines in a manufacturing system can be depicted from a graph-theoretic point of view (machines=nodes, material flow=links).

However, measuring robustness as a static constant over time seems inappropriate for manufacturing systems. As it was found for other real-world systems (Braha & Bar-Yam 2006), the investigated nodes of the network (in our case a node represents a work station in the manufacturing system) seem to change their roles over time. We therefore investigate the appropriateness of a proposed network measure for robustness in manufacturing systems under dynamic conditions.

2. Robustness in Manufacturing Systems

Robust production control methods are control methods to organize release and routing of production orders in a way that fluctuations and disturbances do not negatively influence the performance of the manufacturing system. In (Telmoudi et al. 2008), a framework for robust control laws in manufacturing is suggested and manufacturing system robustness is defined as "its aptitude to preserve its specified properties against foreseen or unforeseen disturbances". Tolio et al. present a framework for robust production control in which they suggest to consider uncertainties when scheduling local resources (Tolio et al. 2011). Other approaches suggest methods for robust planning and scheduling of production orders. Such methods provide production schedules that anticipate potential fluctuations and disturbances and thus result in a better performance under uncertainty. In (Kouvelis et al. 2000), the authors define the task of robust scheduling as "determining a schedule whose performance (compared to the associated optimal schedule) is relatively insensitive to the potential realizations of job processing times" and they develop an optimization approach to hedge against uncertainty of processing times. Goren and Sabuncuoglu (2008) define "a schedule whose performance does not significantly degrade in the face of disruption" as being robust, propose performance measures for the robustness of schedules and further analyze the quality of the proposed measures using a tabu search-based scheduling algorithm. Another approach suggests determining robust production plans by integrating constraints in the stochastic capacitated lot-sizing problem, to ensure that a specific target customer service level is met with high probability (Nourelfath 2011).

Determining the long-term adequate amount of resources in a manufacturing system in a way that the system is rendered robust against certain influencing factors can be described as robust dimensioning or robust capacity allocation. Scholz-Reiter et al. (2011) use a queuing network which they approximate by a fluid model to measure robustness of capacity allocations using the stability radius (a measure commonly used in fluid networks). The stability radius describes the smallest change of parameter that destabilizes a system. In a more holistic approach, we previously suggested to consider robustness in manufacturing systems as an overall system characteristic rather than in terms of schedule performance, and thus to measure it in terms of logistics performance values of the entire system, such as due date reliability, throughput-times or utilization (Meyer et al. 2013).

3. Assessing System Robustness using Network Measures

A network and its elements can be easily represented as a mathematical graph, i.e. as vertices (nodes) and edges (links). Therefore using graph theoretical or statistical mechanics measures to investigate networks has become increasingly popular in the last decade. Research in this field has identified different network models, such as small-world (Watts & Strogatz 1998) or scale-free networks (Barabási 1999). It has been also been revealed that these network models can describe a number of different real-life systems, such as the World Wide Web or social networks (Barabási 1999). Thus researchers in the past increasingly used complex network measures to extensively investigate the characteristics of different natural and man-made networks. One of the many characteristics of interest in this context is network robustness. It has been shown that e.g. scale-free networks display an unexpectedly high degree of robustness against errors (Albert et al. 2000; Callaway et al. 2000; Bollobás & Riordan 2004). In this context, robustness is measured as the change in network diameter (defined as the average minimal path length between any two nodes) when a small fraction of the networks nodes is removed (Albert et al. 2000). This approach has been taken up by several scientists in different fields, e.g. Jeong et al. (2000) observe in metabolic networks that they display insensitivity to the removal of random links, using also the network diameter as a robustness indicator.

But also the robustness of more economically oriented networks, such as worldwide supply chains, has been analyzed using complex network measures. Meepetchdee and Shah (2007) measure supply chain robustness as the extent to which the supply chain is still able to fulfill demand despite damage (removal of nodes) done to the logistical network. They find that in supply chains, a trade-off between robustness and both complexity and efficiency exists. A further suggested robustness measure for supply chains is the behavior of the average node degree of the network under node deletion (Xuan et al. 2011).

It has been argued in various approaches that the network of work stations in a manufacturing system can also be considered as a graph (with nodes representing work stations and links representing material flow) (Becker et al. 2013, to appear; Vrabič et al. 2012; Vrabič et al. 2013). In Liu et al. (2011), the authors suggest to measure the robustness of a manufacturing system by using the clustering coefficient and the average shortest distance. They implement these measures as objectives into a nonlinear optimization approach to find an optimal resource allocation with high robustness and low costs.

However, most of the presented approaches measure robustness as a static characteristic, i.e. they measure average network values (e.g., number of nodes) over a longer period of time. Yet is has been shown that in certain networks (e.g., social communication networks), the roles of the different nodes in the network change over time (Braha & Bar-Yam 2006). In manufacturing networks, the links between the nodes (machines) represent material flow, which can vary drastically depending on the order spectrum in the analyzed time-span. Thus the significance of certain nodes for the robustness of the whole manufacturing network might also change dynamically. The aim of this paper therefore is to analyze what influence the dynamic behavior of the manufacturing system has on the quality of a suggested network measure for robustness in manufacturing systems.

4. The Manufacturing Systems Network Model

When we refer to manufacturing systems, we consider a set of work systems, which are interlinked by material flow among them. The work systems form a logical and organizational entity for the manufacturing of products and are usually also located close to each other, e.g. on a shop floor or on a production site. A work system can be any kind of physical or organizational treatment of material of products, e.g. a drilling machine, an assembly station, quality inspection, or a buffer.

The network representation of a manufacturing system is a directed graph $G = (V, E)$ that consists of a set of nodes (vertices) $V = \{v_1, \dots, v_{|V|}\}$ with the length of $|V|$ and a set of links (edges) $E = \{(v_i, v_j), \dots, (v_y, v_z)\}$ between a selection of node pairs with a length of $|E|$. Each work station in the manufacturing systems is a single node, whereas a material flow between two work stations is represented by a directed link (i.e. $\exists(v_a, v_b)$ if there is at least one product which is routed directly from v_a to v_b). This results in a binary representation of the material flow, regardless of its intensity. To add more information about the material flow, a link $(v_i, v_j) \in E$ can be assigned a link weight, which indicates how many products have been routed directly between the two work stations. The binary representation of links is sufficient to describe the topology of a manufacturing system network, so that analyses regarding connectivity, shortest paths, source-sink-relations, etc. can be conducted. If links are attributed a volume, the network model has a stronger emphasis on the operational processes in the system by quantifying the activity at each link.

The network modeling of a manufacturing system allows for the application of standard graph theoretic measures to describe the topology of a manufacturing system. As we focus on the robustness of manufacturing system, we restrict our description of possible key figures to those who are relevant for the robustness considerations we will suggest in the following.

The in-degree $deg^{-}(v)$ of a node v is the number of incoming links at a node and indicates to how many upstream resources a work station is directly connected. Similarly, the out-degree $deg^{+}(v)$ denotes the number of outgoing links and refers to the number of downstream resources that are linked directly to the observed work station. Consequently, the degree $deg(v)$ is the sum of incoming and outgoing links.

5. Manufacturing Systems as Dynamic Networks

The work systems of a manufacturing system and the material flow make up a directed network, because every material flow defines a mutual interaction between two entities of the system, for which a strict timely order exists. If we consider all material flows that have occurred in an observed time span, or if we consider all hypothetical material flows derived from the route sheets of the company's product portfolio, we get a static representation of the interactions within the manufacturing system. This network representation of the manufacturing system has a distinct topology, which can be the basis for further analysis. However, there is no dynamical component in this particular view on manufacturing systems. This is a major drawback of the static network approach, because manufacturing systems consist on the one hand of relatively persistent elements, the work systems, but on the other hand also of substantially temporal elements, namely the individual processes and operations on the network.

An extension of the previously presented network model is the consideration of the dynamic development of a manufacturing system over time. If we have an observation period from $1 \ldots T$ with a time unit length of u, we are able to slice the observation period into T equally sized time bins. Now we can define a graph G_t for each $t = 1 \ldots T$ with $G_t = (V, E_t)$. The set of links E_t now contains only links (v_a, v_b) if the material flow occurred in period t. The set of nodes remains unchanged, because the work systems are still part of the manufacturing system, even if there has been no in- or outbound material flow in the selected period.

6. Case Study

In our case study, we are going to address three main questions regarding robustness in dynamic manufacturing networks:

1. What is the appropriate time scale for the analysis of robustness in dynamic manufacturing networks?
2. How different are manufacturing networks in their time-dependent behavior?
3. How does the robustness of parts of the network develop dynamically over time?

Feedback data from the scheduling and control software of six different manufacturing companies serves as input data for our case. The six companies operate in tool manufacturing with a job-shop type manufacturing environment, in process industry, or in customization of cars. The observed time period is one year (company E: 3 months). Table CS1 shows a summary of the data sets.

Table CS1: Characteristics of the analyzed data sets. The number of work stations is indicated by the number of nodes in the network. The number of links depicts the number of material flow connections in the static network of the complete observation time.

company	type	nodes	links	no. of operations
A	job-shop	220	1944	77,119
B	job-shop	50	661	28,294
C	job-shop	102	1098	60,081
D	Process	197	1412	175,609
E	job-shop	102	364	2,329
F	customizing	87	999	504,825

Each data set consists of a list of all operations throughout the observed time period. Weekends have been removed from the data, except for company D, which operates 7 days per week. Each operation-record contains the ID of the operation's manufacturing order, the name of the work station the operation was performed on, and the time the operation was executed. We generate the network representation G of the manufacturing system by extracting all work systems and assigning them to the set V. The set E is filled with all material flows by extracting all pairs of worksystems from two consecutive operations of the same manufacturing order. Figure 1 depicts a graphical representation of the manufacturing network of company B over the entire observation period. Time-dependent network representations G_t are composed analogously, but by considering only the operations within period t when creating E_t.

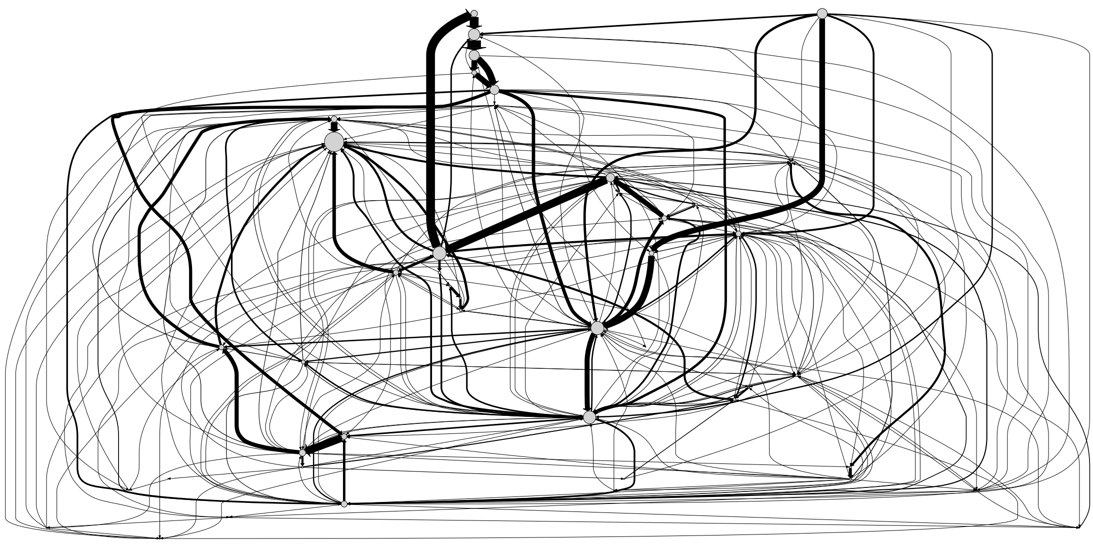

Figure 1 The network representation of company B's manufacturing operations. The line thickness indicates the edge weight, i.e. the number of material flows.

Our first question addresses the identification of an appropriate time scale for the analysis of manufacturing network dynamics. We selected the edge correlation as an indicator for network dynamics, as proposed by (Braha & Bar-Yam 2006) for the analysis of communication in a large social network. We compute the edge correlation by collecting the edge weights of all possible pairs of nodes for the selected time periods in a vector and determining the correlation between all vectors. If there is no material flow between two nodes in a period, the edge weight is 0. Otherwise, the edge weight is the number of material flows in that period.

We select values of 1, 7, 14, 21, and 30 days for u and calculate the average for all correlations between each pair of vector elements to get the average edge correlation of a network for a certain time scale u. Figure 2 shows the results of our analysis. The first observation is that the dynamic networks statistics only differ significantly for small values of u, i.e. for $u = 1$. This means that if we slice the manufacturing operations into weekly, biweekly, or monthly periods, the material flows are highly similar. As opposed to this, a period of one day makes the networks distinguishable over time. Additionally, the average correlation at $u = 1$ strongly differs among the observed networks. The network pattern of companies A and B vary over time, while companies D and E show a relatively stable network pattern. Referring to our initial question, we conclude that only a small time scale, preferably of one day, is suitable for the analysis of dynamics in manufacturing systems.

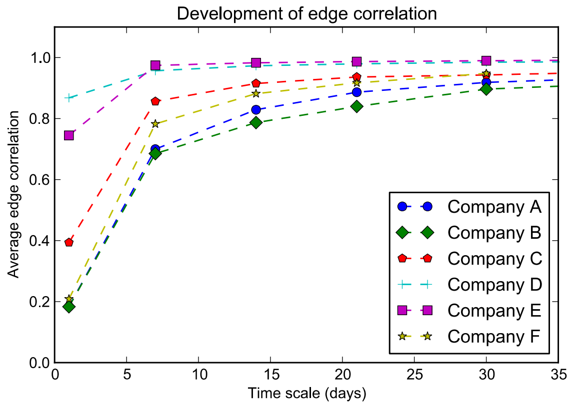

Figure 2: The network similarity, quantified by the average edge correlation, shows that a larger time scale impedes the identification of differences between different time periods of the same network. Only a time scale of 1 day reveals the dynamic development.

The second question focuses on the evaluation of the difference of manufacturing networks over time. The previous analysis has already partially answered this question by indicating that each manufacturing network can have a distinct, quantifiable level of similarity over time. To get a better impression of this phenomenon, we exemplarily visualize the edge correlation of company A and company D as correlation matrices in Figure 3.

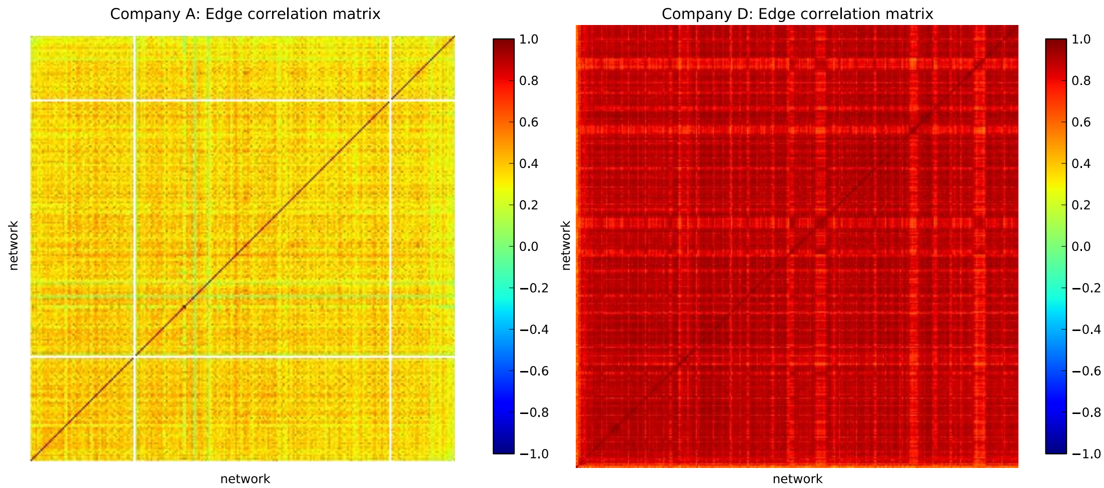

Figure 3: Edge correlation matrices for companies A and D for u=1.

The Figures 3a and 3b visualize the edge correlation for each possible combination of networks G_t. Both axes represent the range of time periods, in this case $t = 260$ for company A and $t = 365$ for company D. By definition, the correlation matrices are symmetric and have a value of 1 for all entries on the diagonal.

As expected from the data in Figure 2, company D exhibits a strong edge correlation of approximately 0.8 throughout the year, while the correlation values of company A are about 0.2 with occasional peaks towards 0.8. Regarding question 2, we state that edge correlation can be used to quantify the self-similarity of a manufacturing network over time. Moreover, the two plots underline the fact that manufacturing networks have a distinct similarity pattern with respect to their dynamic development over time. This implies that the impact of individual nodes on the network's robustness cannot simply be judged by an aggregated, static view of the manufacturing network, but requires an individual consideration depending on the diversity of the network over time.

Our final question aims at evaluating robustness in manufacturing networks over time. We introduce the ratio of remaining operations and overall operations after a node deletion as a robustness measure for the robustness of a network in terms of the deletion of a specific node. This key figure indicates how much a temporary breakdown of a single resource influences the productivity of the manufacturing network. Let o_t be the number of operations of a manufacturing network during period t and $o_{t,w}$ be the number of operations on work station w during period t. Then the robustness indicator $R_{t,w} \in [0,1]$ of the network in period t against the deletion of node w is:

$$R_{t,w} = \frac{o_t - o_{t,w}}{o_t} \quad (1)$$

Thus, a robustness value of 1 is perfect robustness, because the deletion of the selected node does not affect the operations during the observed period. The lower the robustness indicator, the more the complete network is affected by the deletion of node w.

First, we have determined the robustness value for the complete, static network (i.e. with a single period t covering the complete observation period) for each node. The frequency of robustness values for company B is plotted in Figure 4a. The figure illustrates that the individual deletion of a high number of nodes does not significantly affect the manufacturing network's robustness. Only the deletion of few nodes causes more severe disruptions of up to almost 10% of the operations. As a comparison, we plot the frequency of mean robustness after we perform the node deletion on each of the daily dynamic networks and average the robustness value over time. Up to this point, there is no visible difference between applying the measure to the static network or to average values of the dynamic networks. The other companies exhibit similar results.

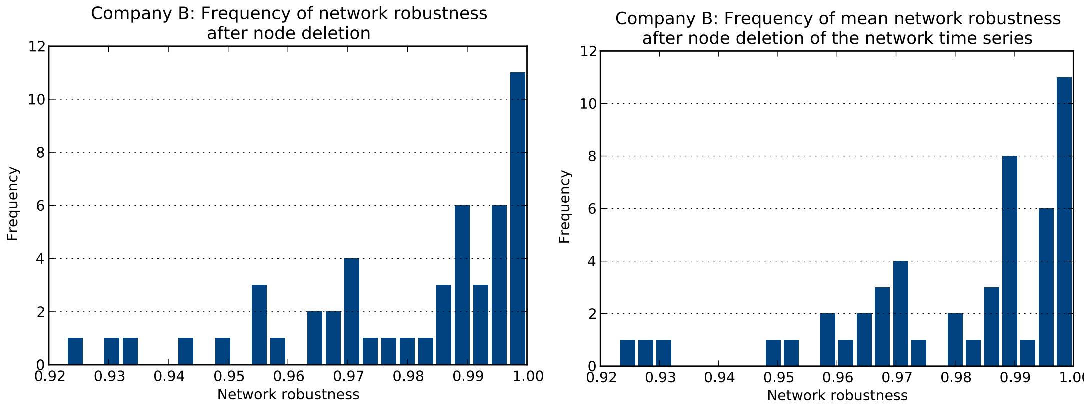

Figure 4: (a) Frequency of robustness against node deletions for all nodes. (b) Frequency of mean robustness against node deletions for all nodes for all dynamic networks over time.

If we take a closer look at the development of the robustness indicator over time, we can see that the network consist of nodes that have less influence on the robustness of the manufacturing network as well as of nodes that have a higher impact on the robustness. However, this influence is not always static. Figure 5 shows the development of the robustness against node deletion for two selected nodes for company B (Figure 4a) and company D (Figure 4b). The node that causes a high variance in robustness passes through different states of robustness (see the black line indicating the moving average), either higher or lower than the robustness value of the static network (dashed line). In contrast, the highly fluctuating robustness of the selected node in company D is much less distinct.

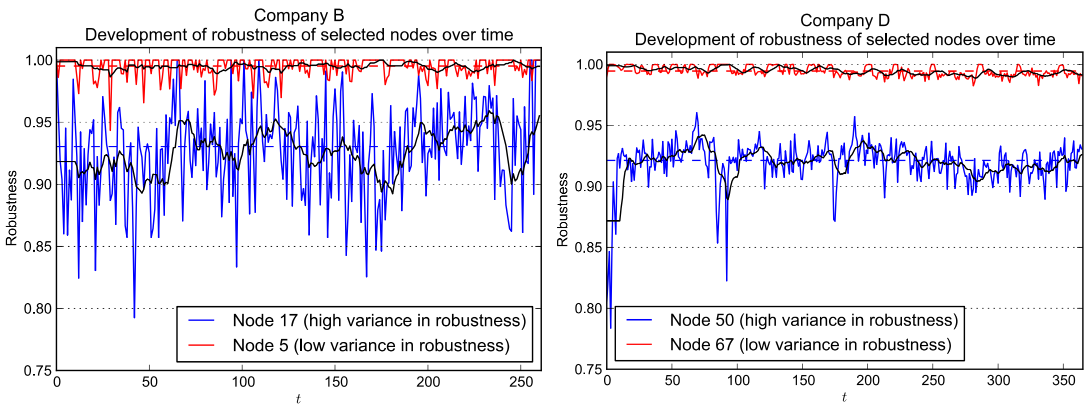

Figure 5: The development of the robustness indicator against the deletion of a selected node varies over time with the dynamic variation of the manufacturing network. (a) Node 5 in company B has less impact on the network's operations, while the robustness against deletion of node 17 fluctuates heavily. The black lines depict the 10-day moving average and the dashed lines depict the corresponding robustness value of the static network. If we observe the moving average of node 17, we see that the robustness value is clearly above or below the static value for longer periods in time. (b) For company D, the robustness fluctuations are significantly lower.

With respect to our last question, we can now state that the robustness of a manufacturing network subject to the deletion of network parts (i.e. work stations) varies over time. If we compare the robustness indicator from the static view on the network and from the dynamic view on the network, it is apparent that the influence of a single node on robustness can vary over time. However, this is not necessarily the case – depending on the individual manufacturing system, the variation of the influence of single nodes on robustness can be low, so that robustness in the corresponding static and dynamic networks is almost equal.

7. Conclusion

Manufacturing systems have been recognized as complex networks of material flow. We have taken this modeling approach and added a dynamic component by slicing the network representation into equally sized time bins. We found that, specifically for manufacturing systems, there is a distinct behavior of material flows over time. The intensity of the differences over time depends on the manufacturing system itself as well as on the selection of the time scale. Our case study has demonstrated that a time scale of one day reveals this distinctness.

With regard to robustness, we were able to show that the consideration of static, aggregated network data can result in misleading conclusions about the influence of parts of the network on robustness. We introduced a robustness indicator, which depicts the robustness of a manufacturing network against deletion of selected nodes. If this measure is applied as a function over time to the dynamic network representation of a manufacturing system, it is able to reveal in which periods the breakdown of a node threatens the performance of the manufacturing system to a greater or lesser extent.

This means that if manufacturing system characteristics such as robustness are gathered, it is necessary to check whether the system changes dynamically over time and to take this development into consideration. We expect that the same applies to other manufacturing systems characteristics, especially if the system shows a high degree of dynamic behavior in general.

References

Albert, R. & Barabási, A.-L., 2002. Statistical mechanics of complex networks. *Reviews of Modern Physics*, 74(1), pp.47–97.

Albert, R., Jeong, H. & Barabási, A.-L., 2000. Error and attack tolerance of complex networks. *Nature,* 406(6794), pp.378–382.

Barabási, A.-L., 1999. Emergence of Scaling in Random Networks. *Science*, 286(5439), pp.509–512.

Becker, T., Meyer, M. & Windt, K., 2013. A Manufacturing Systems Network Model for the Evaluation of Complex Manufacturing Systems. *International Journal of Performance and Productivity Management*, submitted.

Boccaletti, S. et al., 2006. Complex networks: Structure and dynamics. *Physics Reports*, 424(4-5), pp.175–308.

Bollobás, B. & Riordan, O., 2004. Robustness and Vulnerability of Scale-Free Random Graphs. *Internet Mathematics*, 1(1), pp.1–35.

Braha, D. & Bar-Yam, Y., 2006. From centrality to temporary fame: Dynamic centrality in complex networks. *Complexity*, 12(2), pp.59–63.

Callaway, D.S. et al., 2000. Network robustness and fragility: percolation on random graphs. *Physical review letters*, 85(25), pp.5468–71.

Goren, S. & Sabuncuoglu, I., 2009. Optimization of schedule robustness and stability under random machine breakdowns and processing time variability. *IIE Transactions*, 42(3), pp.203–220.

Goren, S. & Sabuncuoglu, I., 2008. Robustness and stability measures for scheduling: single-machine environment. *IIE Transactions*, 40(1), pp.66–83.

Jeong, H. et al., 2000. The large-scale organization of metabolic networks. *Nature*, 407(6804), pp.651–4.

Kitano, H., 2004. Biological robustness. *Nature reviews. Genetics*, 5(11), pp.826–37.

Kouvelis, P., Daniels, R.L. & Vairaktarakis, G., 2000. Robust scheduling of a two-machine flow shop with uncertain processing times. *IEE Transactions*, 32(5), pp.421–432.

Liu, L. et al., 2011. Resource allocation and network evolution considering economics and robustness in manufacturing grid. *The International Journal of Advanced Manufacturing Technology*, 57(1-4), pp.393–410.

Meepetchdee, Y. & Shah, N., 2007. Logistical network design with robustness and complexity considerations. *International Journal of Physical Distribution & Logistics Management*, 37(3), pp.201–222.

Meyer, M., Apostu, M.-V. & Windt, K., 2013. Analyzing the Influence of Capacity Adjustments on Performance Robustness in Dynamic Job-shop Environments. In *Procedia CIRP*. Elsevier B.V., pp. 449–454.

Nourelfath, M., 2011. Service level robustness in stochastic production planning under random machine breakdowns. *European Journal of Operational Research*, 212(1), pp.81–88.

Scholz-Reiter, B., Toonen, C. & Tervo, J.T., 2011. Investigation of the Influence of Capacities and Layout on a Job-Shop-System's Dynamics. In H.-J. Kreowski, B. Scholz-Reiter, & K.-D. Thoben, eds. *Dynamics in Logistics*. Springer, pp. 389–398.

Telmoudi, A.J., Nabli, L. & M'hiri, R., 2008. Robust control of a manufacturing system: Flow-quality approach. In *2008 IEEE International Conference on Emerging Technologies and Factory Automation*. IEEE, pp. 137–142.

Tolio, T., Urgo, M. & Váncza, J., 2011. Robust production control against propagation of disruptions. *CIRP Annals - Manufacturing Technology*, 60(1), pp.489–492.

Toonen, C. et al., 2012. Impact of Machine-Driven Capacity Constellations on Performance and Dynamics of Job-Shop Systems. In H. A. ElMaraghy, ed. *Enabling Manufacturing Competitiveness and Economic Sustainability*. Berlin, Heidelberg: Springer, pp. 611–616.

Vrabič, R., Husejnagić, D. & Butala, P., 2012. Discovering autonomous structures within complex networks of work systems. *CIRP Annals - Manufacturing Technology*, 61(1), pp.423–426.

Vrabič, R., Škulj, G. & Butala, P., 2013. Anomaly detection in shop floor material flow: A network theory approach. *CIRP Annals - Manufacturing Technology*, 62(1), pp.487–490.

Watts, D.J. & Strogatz, S.H., 1998. Collective dynamics of "small-world" networks. *Nature*, 393(6684), pp.440–2.

Xuan, Q. et al., 2011. A Framework to Model the Topological Structure of Supply Networks. *IEEE Transactions on Automation Science and Engineering*, 8(2), pp.442–446.

Performance benchmarking of manufacturing networks within corporations in the steel industry

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Abstract

Manufacturing networks of multinational corporations (MNCs) follow different production strategies. The applied production strategy can vary within manufacturing networks of corporations and has to be considered by benchmarks of manufacturing networks. However, most approaches do not consider the different production strategies within manufacturing networks of corporations, thus fail to take into account the individual goals and priorities of each manufacturing network. In this paper the best-possible production strategy for a manufacturing network in the steel industry is determined by an empirical investigation and a conceptual approach. Based on the defined production strategy an evaluation-logic is derived, which allows to benchmark different manufacturing networks with individual production strategies.

Keywords: Manufacturing network, production strategy, benchmarking, evaluation, steel industry

1. Introduction

Nowadays technology oriented multinational corporations (MNCs) own different manufacturing facilities in various countries. Depending on the target market MNCs produce in complex and inter-connected manufacturing networks their goods for the customers. Pursuing the objective of holistic and continuous manufacturing improvements within all manufacturing networks, it is not adequate any more to evaluate and plan the performance of solely manufacturing facilities. In order to achieve high performance, MNCs have to evaluate and plan their performance on a network level. The purpose of this paper is to present a consistent and practical approach that allows evaluations of manufacturing networks based on a determined production strategy for each manufacturing network in the steel industry.

A manufacturing network is a composition of autonomous or internal production units, which are cooperating in order to complete customer orders which cannot be completed by a single unit (Ahlert, 2007). Each manufacturing network can follow its own production strategy (s. Figure 1). This fact makes it extremely difficult to compare manufacturing performance of different networks with the objective of identifying best practices.

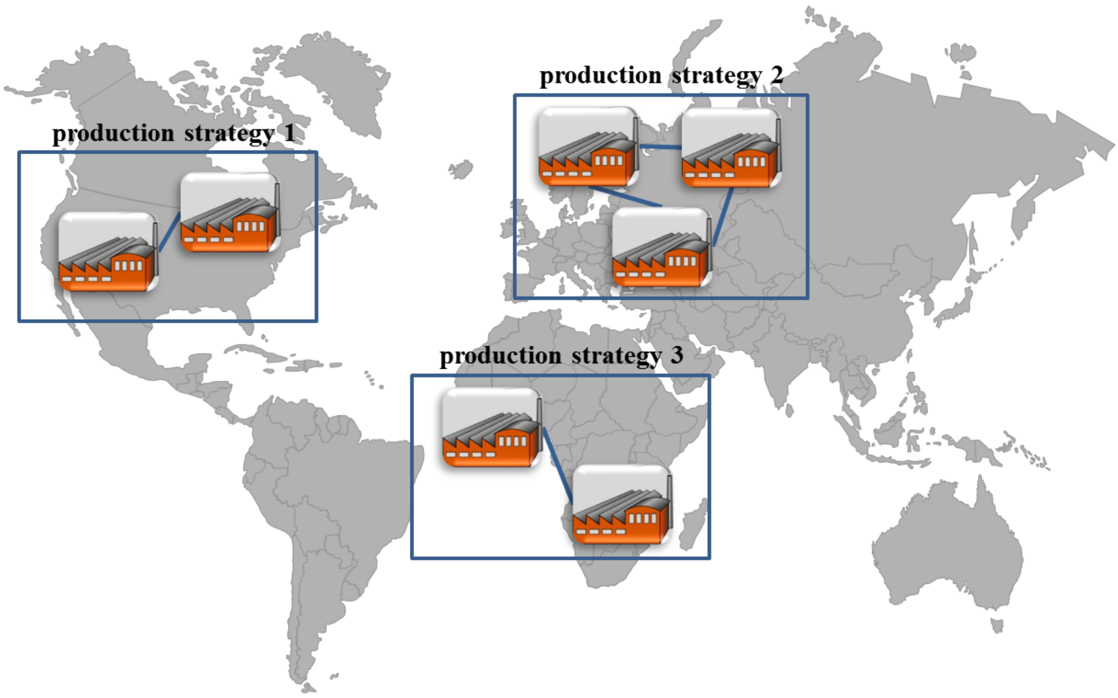

Figure 1. Manufacturing networks with their individual production strategies

For the following work of this paper, a production strategy is defined by its allocation of production orders to different production sites within one manufacturing network. Typically a production order in the steel industry passes on its production route several sites. With regard to the assignment of production orders to different production sites diverse allocation criteria have to be considered. Depending on several influencing factors for each analysed manufacturing network four production strategies can be determined, a *cost*-, *performance*-, *quality*- or *stock-optimal strategy*. When comparing different steel industry specific supply chain management software solutions it can be noted that the order allocation is often carried out by a *cost-optimal production strategy* (Heidrich, 2004). In the context of the cost-optimal production strategy all possible combinations of production sites with associated alternative machines per site along the production route are viewed sequentially. When analysing the alternative routes, production and logistics costs per production order have to be calculated. Logistics costs are only taken into account, when material is produced at several sites. Next, the cost-minimal production route can be chosen. Then it needs to be proved that the route does not result in a bottleneck. In case of a bottleneck the next cheapest production route will be chosen. Special allocations of materials to production machines at one site by their output performance are one of the operation's features of the steel industry. Depending on the product type different production times are required at the same machine. In context of the *performance-optimal production strategy* the manufacturing machines are prioritised in a way that the shortest production time is achieved. In some cases also the *stock-optimal production strategy* can be considered. Depending on the stock level the production output can be reduced by shortening input. In the context of the *stock-optimal production strategy* the output rate can be reduced by several ways. Possibilities are the reduction of production volume or the allocation of materials to low-speed lines along the production route. This production strategy can be implemented in order to reduce the stock level particularly of finished goods in warehouses. After that the reduced production output can be compensated by an excessively high stock level. Moreover, it is technically possible to produce products on alternative machines, where the product quality can differ. In the context of the *quality-optimal production strategy* the materials are allocated to machines by a model which estimates the individual quality of each product per machine.

After determining the adequate production strategies for the considered manufacturing networks, the manufacturing performance of each network has to be continuously controlled and evaluated. Performance improvements within manufacturing networks of MNCs can only be reached, if performance shortfalls are noticed and the right corresponding actions are taken as soon as possible. Best practices have to be identified and applied to poorly performing manufacturing networks. Performance measures support decision-makers to evaluate their manufacturing performance and the implementation of the production strategy into the manufacturing network (Braz et al., 2011; Neely, 1994). The importance of performance measures differs from each manufacturing network based on the chosen production strategy for each manufacturing network. This has to be considered in evaluations and benchmarks.

Enabling decision-makers of MNCs to evaluate and benchmark the performance of their manufacturing networks, an overabundance of apparently important performance measures is not appropriate. Identifying the overall performance of each manufacturing network is therefore highly challenging. From the literature of performance evaluation and benchmarking there is no generally known approach that allows the aggregation of different measures into a single index of overall performance (Gopal & Thakkar, 2012; Wong & Wong, 2008; Shepherd & Günter, 2006). In addition, most methods are not able to account for relative importance of performance measures, which varies among manufacturing networks (Wong & Wong, 2008)

In order to enable decision-makers of manufacturing networks to take the right actions based on an evaluation and benchmarking result, the following four requirements have to be satisfied:

1. Supporting the determination of a production strategy: Decision-makers have to be provided with an approach to determine their appropriate production strategy for their manufacturing network.
2. Considering individual production strategies: Consideration of the production strategy of each manufacturing network in the evaluation and benchmarking process. The individual importance of performance measures at the level of each manufacturing network has to be taken into account.
3. Providing an overall performance: Decision-makers should be provided with an overall performance measure for each considered manufacturing network.
4. Providing a simple approach: The developed approach should be easy to understand in order to promote the application in practice.

This paper presents an approach that satisfies the above requirements. The structure of the paper is as follows: Chapter 2 provides a brief description about the methodological background of this paper. In chapter 3 influencing factors with their corresponding values are presented, which provide the basis for determination of the adequate production strategy for each manufacturing network. In chapter 4 different performance measures are derived from the previously determined production strategies. Chapter 5 presents a novel mathematical method, which provides decision-makers to evaluate and benchmark the performance of manufacturing networks under consideration of their individual production strategy. On this basis the manufacturing performance of each network can be controlled and evaluated steadily. Finally, the presented and developed work is applied in a case study. Figure 2 summarises the proceeding of this paper.

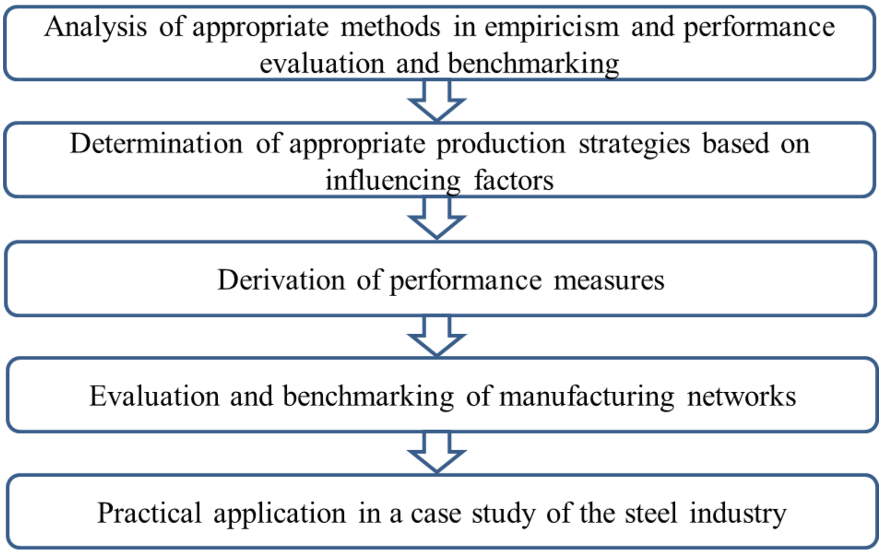

Figure 2. Structure of the paper

2. Methodological background

In the following chapter 2 different empirical research methods will be described briefly. These can be used for the determination of production strategies for each manufacturing network (s. chapter 1). In the second part of this chapter different mathematical methods of performance evaluation and benchmarking are analysed based on their applicability for satisfaction of the predefined requirements in chapter 1.

2.1 Empirical Methodology

Methodologies employed in logistics and supply chain management have been changed in the last time. More and more researchers tend to use survey-based approaches to analyse aspects of this field (Craighead et al., 2007). Required data to be analysed can be collected using survey, experimental or case research. In context of experimental research variables are manipulated by researcher. Case research is studying a phenomenon within different settings. In context of survey research opinion of people or groups is analysed using questionnaire or interview surveys or even mixed forms. With regard to assignment of production strategies to different situations within a network several strategies can be appropriate. To find the right production strategy of each manufacturing network it makes sense to ask several production experts and look for their consensus. Therefore, survey research is the most appropriate method for this aim. When preparing a survey, it has to be decided which rating scale is the most suitable one. Common rating scales are the binary, semantic differential, Guttman and Likert scales. Binary scale is a scale for measuring categorical data consisting binary items. Binary items can take one of two possible values (e.g. yes or no). Semantic differential scale is a multi-item scale. By means of this scale it is possible to indicate an opinion towards a single statement using different pairs of opposite adjectives. Guttman scale is a composite scale, which is designed by Louis Guttman. The scale consists of series of items, which are presented from least intensity to most intensity. Items are differently weighted depending on their intensity. The Likert scale is one of the most popular rating scales. By means of this scale it is possible to indicate own extent of agreement or disagreement regarding a statement. The Likert scale can be ranged, e.g., from “strongly agree” to “strongly disagree”

(Bhattacherjee, 2012). In order to provide the experts the possibility to choose the most appropriate production strategy for a specific scenario of a manufacturing network, all proposed production strategies can be prioritised among each other. The Likert scale is the best for this intent, because its items can be used as priorities per scenario. In this context the scale can be ranged from “priority 1” to “priority 5” for each proposed production strategy per scenario.

2.2 Mathematical methods for performance evaluation and benchmarking

The most commonly used approaches in performance evaluation and benchmarking of different alternatives in the area of manufacturing and logistics can be classified as mathematical methods and are as follows:

- Regression Analysis (RA)
- Stochastic Frontier Analysis (SFA)
- Data Envelopment Analysis (DEA)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

A. Regression Analysis (RA)

RA is a statistical method, which describes a connection between performance measures (the dependent variables) and influencing factors (the independent variables) in the form of a mathematical function, e.g., the simplest form is a linear function. However, it is not possible with it to determine an overall performance of different alternatives—in our case, e.g., the performance of different manufacturing networks.

B. Stochastic Frontier Analysis (SFA)

SFA is in its concept very similar to the RA, but considers statistical errors in its calculations. Based on the calculated error term ε, the mathematical function between performance measures (the dependent variables) and influencing factors (the independent variables) is extended. Besides, SFA is also not appropriate for determining an overall performance. With its calculations it is even more complicated than RA, which therefore does not promote the simple application in practice.

C. Data Envelopment Analysis (DEA)

DEA was first used by Charnes, Cooper and Rhodes to measure the relative performance of homogenous set of decision-making-units—in our case, e.g., the performance of manufacturing networks (1978). There are different variations of DEA, but usually the relative performance of each decision-making-unit can only be calculated by complex linear programs, which is hindering DEA to become a widespread and common tool in practice. Even though, the relative performance can be interpreted as an overall performance of each decision-making-unit.

D. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS was introduced by Hwang and Yoon (1981), which has been already applied in many manufacturing or other operational related topics (Behzadian et al., 2012). Its calculation is considerable easier to understand in comparison to other methods, e.g., DEA. Therefore it is more appropriate to apply it in practice. The result of TOPSIS is a mathematical calculated ratio for each evaluated alternative, which can be defined as an overall performance index. Within all presented methods, TOPSIS is the most appropriate one to determine an overall performance index in a way, which is easy to understand and applicable in practice. The importance of performance measures is considered through weightings, but in the standard TOPSIS approach weightings are for each manufacturing network the same. Therefore the method has to be developed further in order to consider individual importance of performance measures based on the defined production strategy for each manufacturing network.

TOPSIS is grounded on the theory of weighted Euclidean distances. The best alternative, e.g, manufacturing network, is the one, which is simultaneously farthest from the negative-ideal manufacturing network (MN^-) and closest to the positive-ideal manufacturing network (MN^+) values. (MN^-) and (MN^+) are two fictitious manufacturing networks, where the positive-ideal manufacturing network (MN^+) has the best values for all performance measure values, and the negative-ideal manufacturing network (MN^-) all the worst performance measure values within all manufacturing networks. The closer the distance between the performance measure values of an manufacturing network to (MN^+) and simultaneously farer the distance between the performance measure values of an manufacturing network to (MN^-) is, the better is the overall performance index of the considered manufacturing network (MN).

3. Influencing factors and associated production strategies

Based on predefined influencing factors and their corresponding values, one of the four mentioned cost-, performance-, quality- or stock-optimal production strategies are proposed for a manufacturing network. All influencing factors and their values describe key conditions of manufacturing networks in the steel industry. The relevant influencing factors and their corresponding values are presented in the following (s. Figure 3):

Market situation with its values sellers markets and buyers markets is the first influencing factor. In sellers markets customer satisfaction plays a secondary role. The seller sets the rules and delivery times. The most important goal is to increase capacity utilisation and reduce costs. In saturated buyers markets there is a significant competition between suppliers. In those markets the customer decides where he buys the products. In this market the fulfilment of delivery dates and customer wishes are ranked at first (Koether et al., 2011).

Utilisation situation in production networks plays an important role when deciding about a production order allocation. The utilisation situation is influenced by available machine capacities and current backorders (Koether et al., 2011). To assess the utilisation situation in manufacturing networks the capacity has to be defined. In this context, the produced output as a result of existing order backlogs OB can be compared with the capacity limit C_{Limit}. The capacity limit defines which maximal output can be achieved even during demand peaks. Three typical values can be distinguished for the influencing factor Utilisation (s. Figure 3), $C_{Limit} > OB$, chronic bottlenecks and $C_{Limit} < OB$. When an enterprise or manufacturing network ran at a loss, one of the main objectives of the enterprise is to reduce its costs.

Possible cost factors are in the context of this paper production and logistic costs as well as stock inventory costs.

EBIT (earnings before interest and taxes) is one of the most common performance measures to express the financial overall result of a company and is therefore an important influencing factor to determine the adequate production strategy. The financial situation of a company can be viewed by the average EBIT within a defined period of time, e.g., of last 3 years (Lanza, 2009). The corresponding values are defined as either negative or positive EBIT for a specific period of time, e.g., 3 years.

Cash Flow (CF) is also a relevant financial performance measure, which is published by companies. It can be used as an influencing factor for necessary adjustments of the material's stock level (Hill, 2005; Werner, 2013) (s. Figure 3). The corresponding values are defined as either negative or positive CF for a specific period of time, e.g., 3 years.

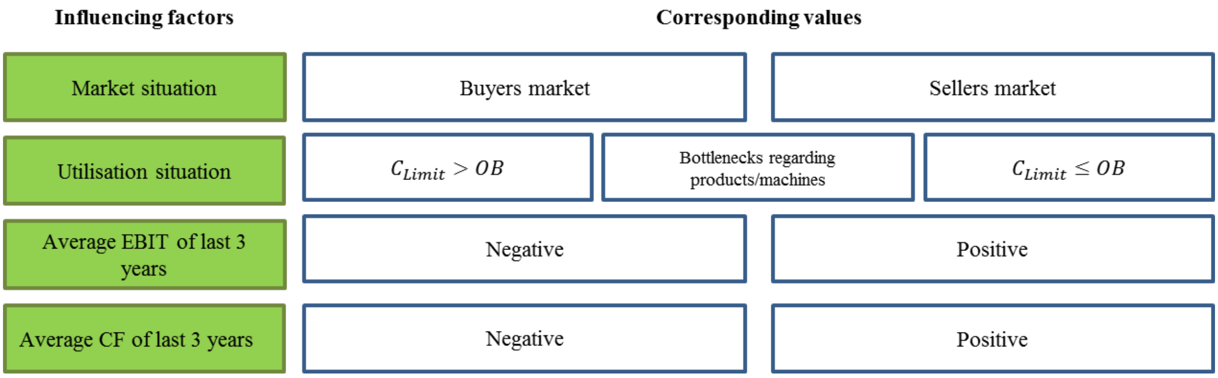

Figure 3. Influencing factors and their values

The maximum number of possible value combinations can be calculated from the product of particular number of values (Meier, 2004). Overall this corresponds to 24 combinations. This complexity can be managed by analysing the validity of possible mathematical combinations. Therefore, combinations "buyers market and $C_{Limit} \leq OB$", "sellers market and $C_{Limit} > OB$", "sellers market and negative EBIT" can be excluded by definition. In this way the number of valid combinations of influencing factors and their corresponding values can be reduced to 12 different scenarios.

Based on a questionnaire, as the applied appropriate empirical method, the proposed production strategies for manufacturing networks in the steel industry are determined. More than 30 production and strategy experts from different manufacturing sites in the steel industry were asked about the appropriate production strategy (cost-, performance-, quality- or stock-optimal) in a manufacturing network for all mentioned 12 scenarios of influencing factors and their corresponding values. With the help of a five point Likert scale the preferred production strategies for each scenario were selected and prioritised by the attendees.

The calculation of the so called consensus factor c per production strategy and scenario was undertaken to test consensus of participants. Consensus factor is the ratio of present variance to maximal possible variance in the surveyed answers of the attendees (Roesselet, 2012).

The result of the survey is presented in the following figures (Figure 4-Figure 5).

Scenario	Influencing factors and relevant characteristics	Prefered production strategies
1	Market situation: **Buyers market** / Sellers market Utilisation situation: **$C_{Limit} > OB$** / Chronic bottlenecks / $C_{Limit} \leq OB$ Average EBIT of last 3 years: **Negative** / Positive Average CF of last 3 years: Negative / **Positive**	• CO is prioritised over SO, PO, QO. • SO, PO, QO are declined by experts.
2	Market situation: **Buyers market** / Sellers market Utilisation situation: **$C_{Limit} > OB$** / Chronic bottlenecks / $C_{Limit} \leq OB$ Average EBIT of last 3 years: **Negative** / Positive Average CF of last 3 years: **Negative** / Positive	• CO is prioritised over SO, PO, QO. • SO is prioritised over PO, QO. • PO, QO are declined by experts.
3	Market situation: **Buyers market** / Sellers market Utilisation situation: $C_{Limit} > OB$ / **Chronic bottlenecks** / $C_{Limit} \leq OB$ Average EBIT of last 3 years: **Negative** / Positive Average CF of last 3 years: Negative / **Positive**	• CO is prioritised over SO, PO, QO. • PO is prioritised over SO, QO. • SO, QO are declined by experts.
4	Market situation: **Buyers market** / Sellers market Utilisation situation: $C_{Limit} > OB$ / **Chronic bottlenecks** / $C_{Limit} \leq OB$ Average EBIT of last 3 years: **Negative** / Positive Average CF of last 3 years: **Negative** / Positive	• CO is prioritised over SO, PO, QO. • SO is prioritised over PO, QO. • PO is prioritised over QO. • QO is declined by experts.
5	Market situation: Buyers market / **Sellers market** Utilisation situation: $C_{Limit} > OB$ / **Chronic bottlenecks** / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: Negative / **Positive**	• PO is prioritised over SO, CO, QO. • SO, CO, QO are declined by experts.
6	Market situation: Buyers market / **Sellers market** Utilisation situation: $C_{Limit} > OB$ / Chronic bottlenecks / **$C_{Limit} \leq OB$** Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: Negative / **Positive**	• PO is prioritised over SO, CO, QO. • SO, CO, QO are declined by experts.
7	Market situation: **Buyers market** / Sellers market Utilisation situation: $C_{Limit} > OB$ / **Chronic bottlenecks** / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: Negative / **Positive**	• PO is prioritised over SO, CO, QO. • SO, CO, QO are declined by experts.
8	Market situation: **Buyers market** / Sellers market Utilisation situation: **$C_{Limit} > OB$** / Chronic bottlenecks / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: **Negative** / Positive	• SO is prioritised over PO, CO, QO. • PO, CO, QO are declined by experts.
9	Market situation: Buyers market / **Sellers market** Utilisation situation: $C_{Limit} > OB$ / **Chronic bottlenecks** / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: **Negative** / Positive	• SO is prioritised over PO, CO, QO. • PO is prioritised over CO, QO. • CO, QO are declined by experts.
10	Market situation: Buyers market / **Sellers market** Utilisation situation: $C_{Limit} > OB$ / Chronic bottlenecks / **$C_{Limit} \leq OB$** Average EBIT of last 3 years: Negative / **Positive** Average CF of last 3 years: **Negative** / Positive	• SO is prioritised over PO, CO, QO. • PO is prioritised over CO, QO. • CO, QO are declined by experts.

CO: Cost-optimal strategy
SO: Stock-optimal strategy
PO: Performance-optimal strategy
QO: Quality-optimal strategy

Figure 4. Questionnaire results: Scenario 1-10

Scenario	Influencing factors and relevant characteristics	Prefered production strategies
11	Market situation: Buyers market / Sellers market Utilisation situation: $C_{Limit} > OB$ / Chronic bottlenecks / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / Positive Average CF of last 3 years: Negative / Positive	• SO is prioritised over PO, CO, QO. • PO is prioritised over CO, QO. • CO, QO are declined by experts.
12	Market situation: Buyers market / Sellers market Utilisation situation: $C_{Limit} > OB$ / Chronic bottlenecks / $C_{Limit} \leq OB$ Average EBIT of last 3 years: Negative / Positive Average CF of last 3 years: Negative / Positive	• QO is prioritised over SO, CO, QO. • SO, CO, QO are declined by experts.

CO: Cost-optimal strategy
SO: Stock-optimal strategy
PO: Performance-optimal strategy
QO: Quality-optimal strategy

Figure 5. Questionnaire results: Scenario 11-12

4. Relevant performance measures for individual manufacturing networks

There is an abundance of performance measures by which the manufacturing network's performance can be evaluated and benchmarked. The key dimensions of manufacturing performance measures are cost, quality, time and flexibility (Neely et al., 1995). The importance of performance measures can differ from each manufacturing network depending on its production strategy. In the context of each production strategy, which is discussed above and derived from the first three dimensions of manufacturing performance, different performance measures can be defined and prioritised. In the following typical performance measures are defined to provide evaluations and benchmarks of manufacturing networks in the steel industry. Within the cost-optimal production strategy allocation costs are measured and prioritised. When analysing the alternative allocation possibilities, production and logistics costs per production order have to be calculated for the manufacturing network. In the context of the stock-optimal strategy, stock level and inventory turnover can be used for performance evaluations (Chan, 2003). In terms of the definition of stock-optimal strategy the focus is placed on finished goods stock. Rejection rate and rate of customer complaints are important key measures, if the product quality is evaluated. The performance-optimal strategy aims to reduce the cycle time within the overall production process of the manufacturing network or to increase the production volume of finished goods. Exemplary all defined performance measures are presented in Figure 6, which were derived out of the production strategy.

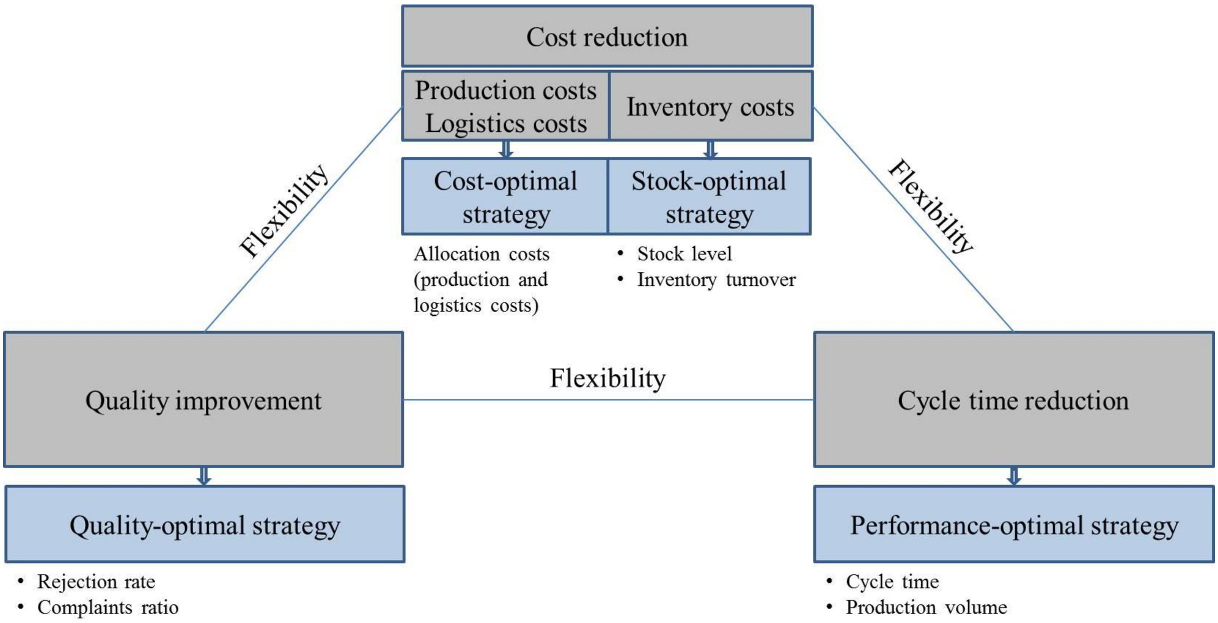

Figure 6. Derivation of performance measures based on the production strategies

The determined production strategy for each manufacturing network and therefore the corresponding prioritisation of performance measures have to be considered in evaluations and benchmarks.

5. Evaluation and benchmarking of manufacturing networks

Based on the determined production strategy of each manufacturing network the performance measures are prioritised. Choosing for example a quality-optimal strategy for a manufacturing network, its performance measures are weighted more than the performance measures, which are allocated to the other production strategies. The weightings a_{ij} for each performance measure (PM_j , j=1,2,…,m) at the level for each manufacturing network (MN_i , i=1,2,….,n) can be calculated by applying the Analytic Hierarchy Process (AHP) using a pairwise comparison (Saaty, 2008). Hence, the weightings a_{ij} describe the relative importance of every performance measure depending on the production strategy at each manufacturing network. The weightings a_{ij} are then transferred into n weighting vectors ($\overline{w}_i$) for each manufacturing network (MN_i):

$$\begin{aligned} \overline{w}_1 &= (a_{11} \quad a_{12} \quad \cdots \quad \cdots \quad a_{1m}) \\ \overline{w}_2 &= (a_{21} \quad a_{22} \quad \cdots \quad \cdots \quad a_{2m}) \\ \ldots &= (\cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots) \\ \overline{w}_n &= (a_{n1} \quad a_{n2} \quad \cdots \quad \cdots \quad a_{nm}) \end{aligned} \tag{1}$$

Afterwards, the performance measures of each manufacturing network are transferred into a $n \; x \; m$ decision matrix (D):

$$D = \begin{pmatrix} m_{11} & m_{12} & \dots & m_{1m} \\ m_{21} & m_{22} & \dots & m_{2m} \\ \dots & \dots & \dots & \dots \\ m_{n1} & m_{n2} & \dots & m_{nm} \end{pmatrix} \tag{2}$$

(D) is then normalised to (X) by applying (3):

$$x_{ij} = \frac{m_{ij}}{\sqrt{\sum_i^n m_{ij}^2}} \tag{3}$$

$$X = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{pmatrix} \tag{4}$$

Then, (X) is multiplied component-wise with each weighting vector $(\overline{w}_i)$ of a corresponding manufacturing network (MN_i) to weighted normalised decision matrices (V_i):

$$V_i = X\,\overline{w}_i = \begin{pmatrix} x_{11}a_{i1} & x_{12}a_{i2} & \dots & x_{1m}a_{im} \\ x_{21}a_{i1} & x_{22}a_{i2} & \dots & x_{2m}a_{im} \\ \dots & \dots & \dots & \dots \\ x_{n1}a_{i1} & x_{n2}a_{i2} & \dots & x_{nm}a_{im} \end{pmatrix} = \begin{pmatrix} v_{11} & v_{12} & \dots & v_{1m} \\ v_{21} & v_{22} & \dots & v_{2m} \\ \dots & \dots & \dots & \dots \\ v_{n1} & v_{n2} & \dots & v_{nm} \end{pmatrix} \tag{5}$$

Further, the "positive-ideal manufacturing network" MN_i^+ and the "negative-ideal manufacturing network" MN_i^- can be determined for each (V_i) as follows:

$$MN_i^+ = \{v_1^+, v_2^+, \dots, v_m^+\}, \qquad \text{positive-ideal manufacturing network} \tag{6}$$
$$MN_i^- = \{v_1^-, v_2^-, \dots, v_m^-\}, \qquad \text{negative-ideal manufacturing network} \tag{7}$$

$$\text{where } v_j^+ = \{(max_i v_{ij} | i = 1, \dots, n), j = 1, \dots, m\} \tag{8}$$
$$\text{and } v_j^- = \{(min_i v_{ij} | i = 1, \dots, n), j = 1, \dots, m\} \tag{9}$$

Afterwards, the weighted Euclidean distances d_i^+ and d_i^- for each manufacturing network with their corresponding (V_i) from the values $(v_{ij})_{i;1\leq j\leq m}$ to the positive-ideal MN^+ as well as negative-ideal manufacturing network MN^- are calculated, respectively, by:

$$d_i^+ = \sqrt{\sum_j^m (v_j - v_j^+)^2} \tag{10}$$

$$d_i^- = \sqrt{\sum_j^m (v_j - v_j^-)^2} \tag{11}$$

The overall performance OP_i for each manufacturing network MN_i is thus determined by:

$$OP_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{12}$$

The larger OP_i is, the better the overall performance of the manufacturing network.

6. Practical application

In the following section a case study is presented to illustrate the application of the concept in practice.

Case Study Description

The case study explores three manufacturing networks in the steel industry, which have to be evaluated respective to their individual production strategy. The first manufacturing network MN_1 consists of three production sites. The manufacturing network MN_1 acts on the buyer's market and is not operating at full available capacity. The annual reports of the last three years show a negative EBIT and a positive CF. Conditions in the second manufacturing network MN_2 with two production sites are the same except in CF. MN_2 recorded a negative CF for the last three years. The last manufacturing network MN_3 with its three production sites acts also on a seller's market. It is producing at full capacity and the annual reports show a sustained gain in EBIT and a harmonious positive development of the CF over the last three years. The following performance measures PM_{1-3} are derived to provide an appropriate evaluation and benchmark of the manufacturing networks MN_{1-3}:

- Allocation costs (the sum of production and logistics costs) per produced quantity (PM_1),
- Inventory turnover (PM_2),
- Complaints ratio (PM_3),
- Cycle time per produced quantity (PM_4),

Table 1 shows all performance measures and their corresponding values for each manufacturing network:

Table 1. Performance measures of each manufacturing network

	Allocation costs/ production quantity	Inventory turnover	Complaints ratio	Cycle time/ production quantity
	PM_1	PM_2	PM_3	PM_4
MN_1	0.86	0.41	0.15	0.030
MN_2	0.82	0.37	0.23	0.028
MN_3	0.78	0.35	0.07	0.027

Identification of the adequate production strategy

The influencing factors for MN_1 correspond to the scenario 1 (s. Figure 4), in which the implementation of the cost-optimal strategy is recommended. Influencing factors in MN_2 reflect scenario 8 (s. figure 4). In order to eliminate the persistent negative cash flow situation in MN_2 the stock-optimal strategy is suggested. The influencing factors in MN_3 correspond to scenario 7, for which a performance-optimal strategy is preferred (s. Figure 4). All influencing factors and their corresponding values as well as the preferred production strategies for MN_{1-3} are summarised in Figure 7.

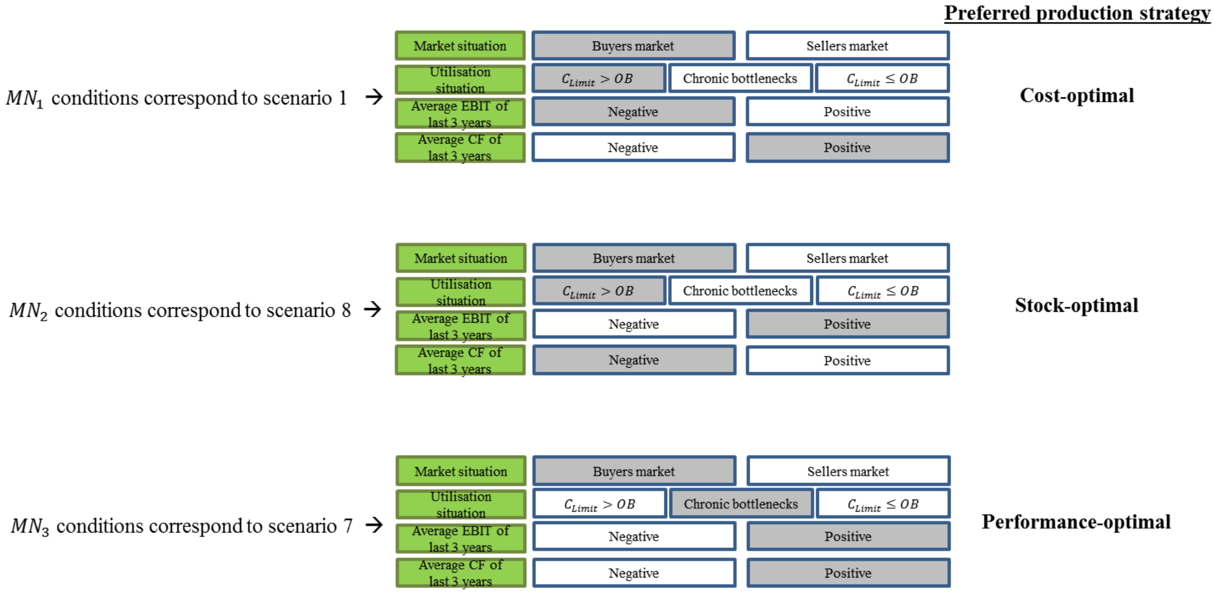

Figure 7. Preferred production strategies for $MN_{1,2,3}$

Evaluation and Benchmarking

According to the identified production strategy for each manufacturing network the performance measures have to be prioritised as follows in Table 2.

Table 2. Prioritisation of Performance Measures for each manufacturing network

Manufacturing Network	*Choosen production strategy*	*Prioritisation of Permance Measures*
MN_1	cost-optimal strategy	PM_1 (allocation costs per produced quantity) has to be weighted stronger than others
MN_2	stock-optimal strategy	PM_2 (inventory turnover costs) has to be weighted stronger than the others
MN_3	performance-optimal strategy	PM_4 (cycle time per produced quantity) has to be weighted stronger than the others

The weightings of the performance measures for each manufacturing network are determined based on the prioritisation of the performance measures by the proposed AHP method (s. Table 3).

Table 3. Weightings for each manufacturing network

		$PM_1{}^*$	$PM_2{}^*$	$PM_3{}^*$	$PM_4{}^*$	$\sum$	$w_{1j,1-4}$
Manufacturing Netwwork 1 (MN_1)	$PM_1{}^{**}$	-	2^c	2^c	2^c	6	6/12=0.50
	$PM_2{}^{**}$	0^b	-	1^a	1^a	2	2/12=0.16
	$PM_3{}^{**}$	0^b	1^a	-	1^a	2	2/12=0.16
	$PM_4{}^{**}$	0^b	1^a	1^a	-	2	2/12=0.16
	$\sum$	0	4	4	4	**12**	
		$PM_1{}^*$	$PM_2{}^*$	$PM_3{}^*$	$PM_4{}^*$	$\sum$	$w_{2j,1-4}$
Manufacturing Netwwork 2 (MN_2)	$PM_1{}^{**}$	-	0^b	1^a	1^a	2	2/12=0.16
	$PM_2{}^{**}$	2^c	-	2^c	2^c	6	6/12=0.50
	$PM_3{}^{**}$	1^a	0^b	-	1^a	2	2/12=0.16
	$PM_4{}^{**}$	1^a	0^b	1^a	-	2	2/12=0.16
	$\sum$	4	0	4	4	**12**	
		$PM_1{}^*$	$PM_2{}^*$	$PM_3{}^*$	$PM_4{}^*$	$\sum$	$w_{3j,1-4}$
Manufacturing Netwwork 3 (MN_3)	$PM_1{}^{**}$	-	1^a	1^a	0^b	2	2/20=0.10
	$PM_2{}^{**}$	1^a	-	1^a	0^b	2	2/20=0.10
	$PM_3{}^{**}$	1^a	1^a	-	0^b	2	8/20=0.40
	$PM_4{}^{**}$	2^c	2^c	2^c	-	6	6/12=0.50
	$\sum$	6	6	0	2	**20**	

[a] PM^{**} is as important as PM^*
[b] PM^{**} is less important than PM^*
[c] PM^{**} is more important than PM^*

The calculated weights w_{ij} are then transferred into the weighting vectors $(\overline{w}_i)$:

$$\overline{w}_1 = (0.50 \quad 0.16 \quad 0.16 \quad 0.16)$$
$$\overline{w}_2 = (0.16 \quad 0.50 \quad 0.16 \quad 0.16)$$
$$\overline{w}_3 = (0.16 \quad 0.16 \quad 0.16 \quad 0.50)$$

Afterwards, the performance measures of each manufacturing network are transferred into a $n\, x\, m$ decision matrix (D):

$$D = \begin{pmatrix} 0.86 & 0.41 & 0.15 & 0.030 \\ 0.82 & 0.37 & 0.23 & 0.028 \\ 0.78 & 0.35 & 0.07 & 0.027 \end{pmatrix}$$

(D) is then normalised to (X) by applying (3):

$$X = \begin{pmatrix} 0.60 & 0.62 & 0.52 & 0.61 \\ 0.87 & 0.56 & 0.81 & 0.57 \\ 0.54 & 0.53 & 0.24 & 0.54 \end{pmatrix}$$

Then, the matrix (X) is multiplied component-wise with each weighting vector $(\overline{w}_i)$ of its corresponding manufacturing network (MN_i) to weighted normalised decision matrices (V_i):

$$\text{For } MN_1: \; V_1 = \begin{pmatrix} 0.302 & 0.100 & 0.084 & 0.097 \\ 0.288 & 0.090 & 0.129 & 0.091 \\ 0.274 & 0.085 & 0.039 & 0.087 \end{pmatrix}$$

$$\text{For } MN_2: \; V_2 = \begin{pmatrix} 0.096 & 0.313 & 0.084 & 0.097 \\ 0.092 & 0.282 & 0.129 & 0.091 \\ 0.087 & 0.267 & 0.039 & 0.087 \end{pmatrix}$$

$$\text{For } MN_3: \; V_3 = \begin{pmatrix} 0.096 & 0.100 & 0.084 & 0.305 \\ 0.092 & 0.090 & 0.129 & 0.285 \\ 0.087 & 0.085 & 0.039 & 0.274 \end{pmatrix}$$

Further, for each manufacturing network MN_{1-3} the "positive-ideal manufacturing network" MN_i^+ and the "negative-ideal manufacturing network" MN_i^- can be determined based on the determined matrices (V_{1-3}) by applying (6)-(9) as follows:

For MN_1: $MN_1^+ = \{0.302,0.085,0.129,0.097\}$, positive-ideal manufacturing network
$MN_1^- = \{0.274,0.100,0.039,0.087\}$, negative-ideal manufacturing network
based on V_1

For MN_2: $MN_2^+ = \{0.096,0.267,0.129,0.097\}$, positive-ideal manufacturing network
$MN_2^- = \{0.087,0.313,0.039,0.087\}$, negative-ideal manufacturing network
based on V_2

For MN_3: $MN_3^+ = \{0.096,0.085,0.129,0.305\}$, positive-ideal manufacturing network
$MN_3^- = \{0.087,0.100,0.039,0.274\}$, negative-ideal manufacturing network
based on V_3

Afterwards, the weighted Euclidean distances d_i^+ and d_i^- between the values v_{ij} of each manufacturing network MN_i from its corresponding V_i and MN_i^+ as well as MN_i^- are calculated, respectively, by applying (10) and (11). The results are as follows (s. Table 4).

$v_{1,1-4}$ of MN_1 from V_1: $v_{1,1-4} = \{0.302, 0.100, 0.084, 0.097\}$
$v_{2,1-4}$ of MN_2 from V_2: $v_{2,1-4} = \{0.092, 0.282, 0.129, 0.091\}$
$v_{3,1-4}$ of MN_3 from V_3: $v_{3,1-4} = \{0.087, 0.085, 0.039, 0.274\}$

Table 4. Euclidean distances d_i^+ and d_i^-

	d_i^+	d_i^-
Distances for MN_1 from V_1 with $v_{1,1-4}$ to MN_1^+ and MN_1^-	0.0474	0.0541
Distances for MN_2 from V_2 with $v_{2,1-4}$ to MN_2^+ and MN_2^-	0.0172	0.0955
Distances for MN_3 from V_3 with $v_{3,1-4}$ to MN_3^+ and MN_3^-	0.0957	0.0146

The overall performance OP_i for each manufacturing network MN_i is thus determined by applying (12) and provided in descending order in the following:

$$OP_2 = 0.8472, \qquad OP_1 = 0.5325, \qquad OP_3 = 0.1329$$

Based on the presented results MN_2 is determined as the best performer within all three manufacturing networks.

7. Conclusion and Discussion

Decision-makers in manufacturing networks of MNCs in the steel industry can often not appropriately assess and evaluate the performance of their manufacturing network. It is important to consider the corresponding production strategy of each manufacturing network, if the performance wants to be evaluated and benchmarked with other manufacturing networks.

This paper presents an approach to determine the adequate production strategy for a manufacturing network in the steel industry based on an empirical investigation. The appropriate production strategy for each manufacturing network is proposed by a developed catalogue of possible scenarios and associated production strategies in the steel industry. With the help of this catalogue the preferred appropriate production strategy for a manufacturing network in the steel industry is selected. Different performance measures can then be defined to evaluate and benchmark the performance of each manufacturing network. Further, these performance measures are prioritised by weightings based on the proposed production strategy for the considered manufacturing network. Applying the presented evaluation and benchmarking method, decision-makers are able to evaluate and benchmark whole manufacturing networks with different production strategies by just one aggregated performance measure. Because of the simple calculations in the developed performance evaluation and benchmarking method, it promotes also the application in practice. Further research is needed to verify, if this approach is also applicable in other industries.

References

Ahlert, K. H., Corsten, H., Gössinger, R. (2007) Kapazitätsmanagement in auftragsorientierten Produktionsnetzwerken—Ein flexibilitätsorientierter Ansatz. In H.-O. Günther, D. C. Mattfeld and L. Suhl (eds.), *Management logistischer Netzwerke*, Heidelberg, Physica-Verlag HD, 113-136.

Andy, N., Mills, J., Platts, K., Gregory, M., Richards, H. (1994). Realizing Strategy through Measurement, *International Journal of Operations & Production Management*, 14/3, 140-152.

Behzadian, M., Khanmohammadi Otaghsara, S., Yazdani, M., Ignatius, J. (2012). A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, 39/17, 13051-13069.

Bhattacherjee, A. (2012). *Social Science Research: Principals, Methods, and Practices*, USF Open Access Textbooks Collection. Book 3.

Braz, R., Gomes, F., Scavarda, L. F., Martins, R. A. (2011). Reviewing and improving performance measurement systems: An action research, *International Journal of Production Economics*, 133/2, 751–760.

Chan, F. T. (2003). Performance measurement in a supply chain, *The International Journal of Advanced Manufacturing Technology*, 21/7, 534-548.

Charnes, A., Cooper, W. W., Rhodes, E. (1978). Measuring efficiency of decision making units, *European Journal of Operational Research*. 2/6, 428–449.

Craighead, C.W., Hanna, J.B., Gibson, B.J., Meredith, J.R. (2007). Research approaches in logistics. Trends and alternative future directions, *International Journal of Logistics Management*, 18/1, 22-40.

Gopal, P.R.C., Thakkar, J. (2012). A review on supply chain performance measures and metrics: 2000-2011, *International Journal of Productivity and Performance Management*, 61/5, 518–547.

Heidrig, J. (2004). *Implementierung von Supply Chain Management Systemen in der Stahlindustrie. Konzept zur Generierung von Schnittstellen zwischen den einzelnen Ebenen hierarchischer Palnungssysteme sowie dem Legacy-System*, Ph.D. dissertation, Technical University of Berlin, Germany.

Hill, R. M., Pakkala, T. P. M. (2005). A discounted cash flow approach to the base stock inventory model, *International Journal of Production Economics*, 93, 439-445.

Hwang, C. L., Yoon, K. P. (1981). *Multiple attribute decision making: Methods and applications*. Berlin et al.: Springer.

Koether, R., Augustin, H.-P. (2011). *Taschenbuch der Logistik*. Munich: Carl Hanser Verlag.

Lanza, G., Weiler, S., Vogt, S. (2009). *Design for low-cost country sourcing: motivation, basic principles and design guidelines - Proceedings of the 19th CIRP Design Conference–Competitive Design*. Cranfield University Press.

Meier, M. (2004). *Der Innovations-Prozess*. SWISS Federal Institute of Technology Zurich, Zurich, Schwitzerland.

Neely, A., Gregory, M., Platts, K. (1995). Performance measurement system design: A literature review and research agenda, *International Journal of Operations & Operational Management*, 15/4, 80-116.

Roesselet, S. (2012). *ExpertInnen machen Schule: Ergebnisse einer Delphibefragung zur Förderung von SchülerInnen mit Migrationshintergrund*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1/1, 83–98.

Shepherd, C., Günter, H. (2006). Measuring supply chain performance: current research and future directions. *International Journal of Productivity and Performance Management*, 55/3/4, 242–258.

Werner, H. (2013). *Supply Chain Management. Grundlagen, Strategien, Instrumente und Controlling*. Wiesbaden: Springer Fachmedien.

Wong, W. P., Wong, K. Y. (2008). A review on benchmarking of supply chain performance measures, *Benchmarking: An International Journal*, 15/1, 25–51.

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A methodology for integrating global value networks – an exploratory study into future industrial sub-systems in next generation pharmaceuticals

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Abstract
This paper aims to explore how complex, multi-tiered value networks, often managed as semi-independent sub-systems, can be better integrated end-to-end. The approach adopts a more holistic approach to industrial system design by analysing opportunities for better integration between the sub-systems that make up the value network.

The approach enables the exploration of the drivers of, and interactions between, the main sub-systems in complex, multi-tier value networks. Cross-sector case data suggests that these networks often comprise semi-independent sub-systems that have evolved over extended time periods but have then become part-disconnected, operating as silos of activity with independent governance and coordination mechanisms.

A methodology is introduced to identify reconfiguration opportunities that support the re-integration of these sub-systems. The approach is applied in an exploratory study into the pharmaceutical value chain involving the traditionally separate Clinical and Commercial supply chains, and their discrete API, Formulation, Pack, Distribute, and final Patient Delivery models. Opportunities for re-integration of these sub-systems are presented and the drivers for end-to-end integration identified.

Key words: Value networks, supply chains, industrial sub-systems

Introduction
Many industries have witnessed the progressive ‘disaggregation’ of their value networks driven by specialisation and the geographic dispersion of key activities. Previous research has provided rich narratives on these changes to industry structure (e.g. Jacobides 2005) focusing on the structural changes driven by outsourcing, off-shoring and technology trends (Mudambi and Venzin 2010). Other researchers have adopted a value chain perspective including the identification of different patterns of specialisation and internationalisation, as firms seek to develop competitive positions across the value network, while seeking to integrate external capabilities and capture the benefits of location. More recently, the disaggregation phenomena has been discussed in terms of the emerging capabilities of new actors that fundamentally change replenishment and business models (Srai and Alinaghian 2013). This more complex fragmented and dispersed network of actors however poses a major challenge in how to analyse, design and configure these increasingly complex industrial systems. This problem is particularly acute in those sectors, where multiple tiers of component and intermediate product manufacturers constitute extended supply networks, providing multiple options on ownership, location, and partnering models (Srai 2013).

The disruptive impacts of new technologies, new routes to market or novel replenishment and business models further complicate the network design task as radically reconfigured value networks become genuine possibilities. However, research on these extended supply networks (Sri and Gregory 2008), often involving high-value manufacturing emerging industries, suggest that these networks often comprise of semi-independent sub-systems that have evolved over extended time periods but have then become part-disconnected, operating as silos of activity with independent governance and coordination mechanisms. Global value network performance is often hindered when these semi-independent sub-systems become disconnected, often as a consequence of changes in key drivers. These sub-systems tend therefore to be optimised at this sub-unit of analysis in stark contradiction to the declared network reconfiguration objectives, namely integrated outcome based supply and value chains. The approach presented in this paper considers a more holistic approach to address this issue of industrial system design in complex multi-tier supply networks by analysing opportunities for better integration between the sub-systems that make up the value network.

Sub-systems analysis and integration

The approach presented here explores of the drivers of, and interactions between, the main sub-systems in complex, multi-tier value networks. A key premise here is that a broader systems perspective can stimulate radical innovation that seeks to optimise value across sub-systems. The opportunity to apply this approach is particularly relevant in multi-tier value networks where sub-systems have emerged to organise effectively across these extended networks, often involving production of sub-assemblies and intermediate products. However, these sub-systems often evolve – and drive innovation and efficiency – independently (mirroring the functional silos sometimes seen in complex single firm organisations), often to the detriment of the end-to-end value network. In many cases, the regulatory frameworks 'lock-in' this structural development.

For example, in Pharmaceuticals, the clinical supply chain 'system' can impose process and regulatory constraints for the full-scale commercial supply chain. In Aerospace, complex component supply chains have emerged at regional and national levels that are not easily scalable to the global markets the primes are faced with serving. The rapid development of substantial intermediate goods supply chains in food, consumer electronics and textiles also provide opportunities for improved value network integration and reconfiguration.

The approach presented here identify opportunities for taking a more end-to-end value network perspective, reconnecting upstream and downstream elements and potentially informing a radical innovation agenda for reconnecting semi-isolated sub-systems. This proactive redesign approach to value network integration and optimisation can be used to direct the product-process research and technology agenda. Alternative product and process models that emerge are then evaluated to identify the scale of opportunity and whether previously established sub-system constraints can be overcome. The approach may suggest radical redefinition of value network drivers, and identifying the breakthrough innovations that might support a paradigm shift in value network performance.

Exploratory cases for systems analysis and integration

A number of cases exploring intervention examples using this approach to develop new or radically different product-process reconfiguration models that can support major breakthroughs in total value network performance were examined. These included exploring continuous-processing and crystallisation in previously batch-process-oriented Pharma, implications of additive manufacturing in component manufacture that replaces traditional subtractive processes, and post-dosing product finishing models that enable more near-market supply. Although none of these models examined have reached industrial viability, as each require significant technology breakthroughs in formulation, production processing and/or delivery models, redesign alternatives and options were considered that might be suitably informed by a broader value network analysis and systems optimisation agenda. These conceptual network redesign studies emphasised different product, process and business models that enable new or previously elusive markets to be served economically.

Methodology

The development of the methodology was informed by exploring three industrial systems using supply and value chain mapping techniques (Srai and Gregory 2008, Srai and Alinaghian 2013). The methodology also involved a proactive value network design and systems integration agenda, informed by respective technology experts, that might directs innovation which support more attractive value network configuration models. This requires capturing the drivers of, and interactions between, the main sub-systems across the value network. Invariably in the application of this approach, the systems boundaries are extended to encompass the extended value network, with the end-user focus most critical in informing potential sub-system trade-offs.

Four key stages were involved in the analysis process. The first involves identifying the barriers to adopting potential alternative product-process technologies and business models that might be used to serve existing markets more effectively or deliver unmet end-user needs. Exploratory cases suggest that barriers may be real or perceived, and arise from combinations of socio-political, technical and regulatory factors. Unmet end-user needs, on the other hand, are either driven by new capabilities that create new markets or known market segments that have been previously considered uneconomical to serve. Personalised medicines or niche product markets were examples where advances in diagnostics, information technologies and digitisation, are enabling more disaggregated value network models that now have the potential to be served economically.

The next stage of the systems integration approach involved sub-system identification, and definition in terms of the critical metrics used to optimise these semi-independent sub-systems. Sub-systems themselves can be identified by current-state supply and value network mapping approaches discussed elsewhere in this report. The approach identifies the drivers and design factors that predominate in each sub-system. An end-to-end value network performance metric analysis then identified the current state configuration design parameters and trade-offs.

The third stage in the analysis process involves exploring alternative value network scenarios that could emerge by adopting alternative product-process-business model innovations. These alternatives may be based on emerging process and production technologies or even technologies that are still yet to be fully developed (such as continuous processing and crystallisation in Pharma). These scenarios may require alternative scale production footprints (dispersed, close-to-market, low-scale integrated plants, for example), or alternative supply models that might now be possible due to advances in ordering or replenishment (such as e-commerce-based last-mile supply chains). In practice, scenarios depend on various disruptive influences that challenge the current value network model and introduce possible product or product-service models.

The final stage is an integrated value network systems analysis that integrates the analysis of the alternative scenarios under consideration, and how they might redefine the sub-systems of the current state configuration. The assessment approach, incorporates the potential benefits of given scenarios as a ‘delta’ analysis (%) on the current state for key system metrics, the value proposition in making the transformation from a business context for key value network players (for example, in absolute terms, the potential impact on revenue, margin, inventory reduction etc) against the investments required, and the technological feasibility of the identified disruption. These three elements of the evaluation are incorporated into a total value network analytical framework.

In this paper we introduce in more detail one of the exploratory cases examined to set out the analysis and results from the approach outlined above.

Exploratory Case Study - Pharmaceutical sector

Healthcare is a particularly good example of an industry sector facing restructuring challenges as current operating models becomes less and less viable. Structural changes are also being driven by technology advances, ageing populations and new approaches to patient care. These changes have the potential to generate very different network configurations featuring increasingly distributed information flows and innovative revenue models.

The sector exhibits the criteria of a multi-tier supply network, established sub-systems of active production, separate formulate production, and final pack, and extended distribution models. Clinical trials supply chains are managed separately from the full-scale commercial supply chains. The regulatory models map these established structures. Governance models revolve around established batch production processes. The sector is characterised by these established sub-systems which are in large part managed independently.

However, at a systems level, the sector suffers from excessively high inventory levels (more than six months at the firm level, and perhaps 18 months end-to-end) compounded by moderate production process quality performance (typically 3 sigma). Institutional customers such as national governments are increasingly reluctant to accept the cost of new drugs whilst the major primes are having to manage a more fragmented product portfolio as new technologies are driving smaller volume production runs targeting more niche markets.

In order to test the methodology an exploratory study using the four stage methodology outlined earlier examined a number of existing and emerging products that may benefit from this systems analysis.

Key findings from the analysis

The four-stage process was used to identify alternative value network opportunities.

1 Barriers, opportunities and identifying unmet needs

Initial research identified a number of drivers and barriers for the implementation of continuous manufacturing in the pharmaceutical industry.

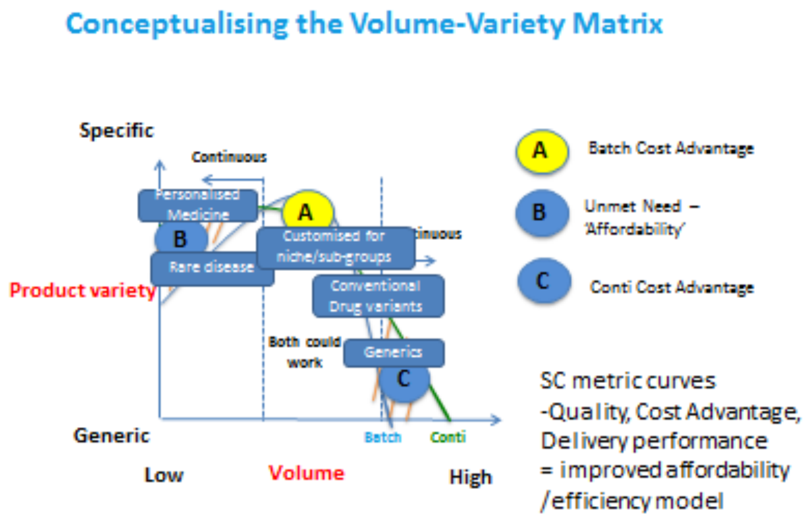
Drivers and opportunities for continuous manufacturing

- Plant footprint reduction by 70%
- CapEx reduction by 25%
- Operating cost reduction by 30%
- Yield improvement by 10%
- More consistent quality
- More controllable, repeatable process

Barriers to the adoption of continuous manufacturing

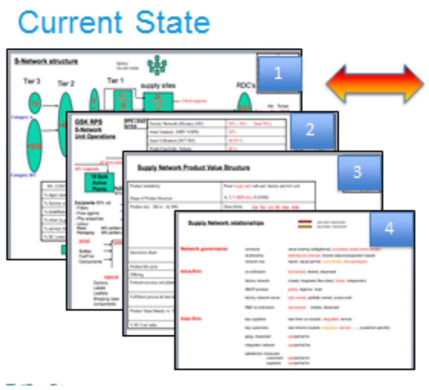
- Regulatory uncertainties
- Under-utilisation of existing capacity
- Technological readiness and uncertainties
- No clear and specific vision as to how CM may impact on industry structure
- Transformation challenge and behavioural issues

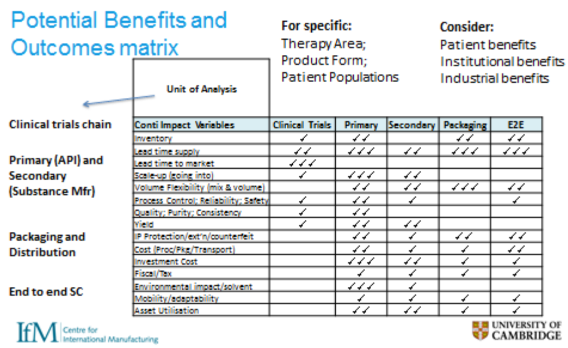
The analysis was then extended to identify at a conceptual level (see Figure below), the potential end-user markets and products where continuous processing technology might provide attractive value network opportunities, either in meeting unmet user needs (position B on the chart) or providing step changes in cost, flexibility or reliability (C).



2 *Current state mapping and benefits metrics analysis*

Current state configuration mapping tools were used to capture sub-systems across the total value network. For each of these sub-systems, a potential benefits matrix was constructed to scale the opportunity for adopting continuous processing. Benefits could accrue to patients, government health service providers and industrial value network partners. These factors were considered in selecting potential products and markets for the adoption of new continuous processing technologies.





3 *Alternative product-process archetype analyses – analysis against desired metrics*

As described earlier, the analysis considered a number of specific drug products for alternative systems network configuration. For each of these products, spanning different firms in the sector, the following dataset was used to inform the analysis, with the data separated into operational data, current and alternative/future processing models, and wider societal considerations that may influence the reconfiguration opportunity;

Operational Data

- Volume
- Revenue
- SKU mix
- Margin
- Inventory
- Capex
- Quality/Waste

Processing model

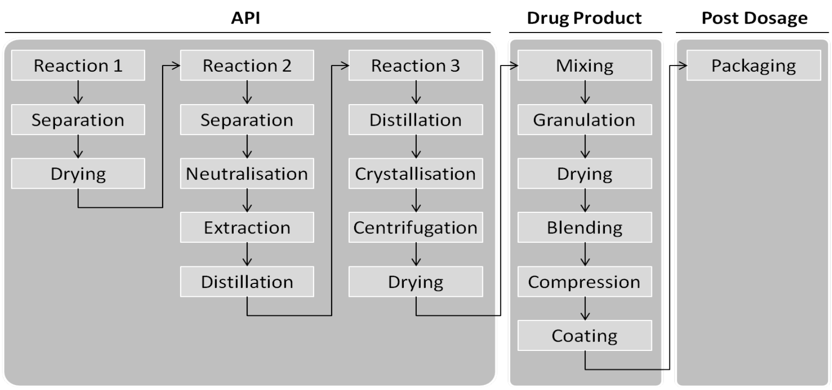
- Current
- Future

Societal importance

- Patient population
- Disease area
- Unmet need
- Affordability

The operational data provided the required baseline dataset, but extended to the extended system boundaries not normally considered in the current network design processes.

The processing models current and future considered the processing steps required at present and alternatives building on a generic processing framework used (see below)



The societal criteria were based on developing the case for network reconfiguration in terms of delivering more affordable drugs, meeting unmet needs or addressing new patient populations. This was a key element of a systems level design that may not be as transparent at the sub-system level.

For selected patient and market segments, value network scenario analysis against critical metrics (identified in step 1 and 2) was undertaken at the sub-system level to identify the scale of the opportunity for continuous processing. This step in the process generates 'the delta' or potential step change possible in the key metric(s) under consideration.

Sub-system definition;

The following sub-systems were identified in this Pharmaceutical study, and for each, the methodology involved setting out the research question in terms of system optimisation, factors of analysis, and desired outcome.

- Volume, Variety Matrix
- Clinical trial Supply Chain
- Primary/Secondary Manufacture
- Packing/Distribution
- End-to End Supply Chain

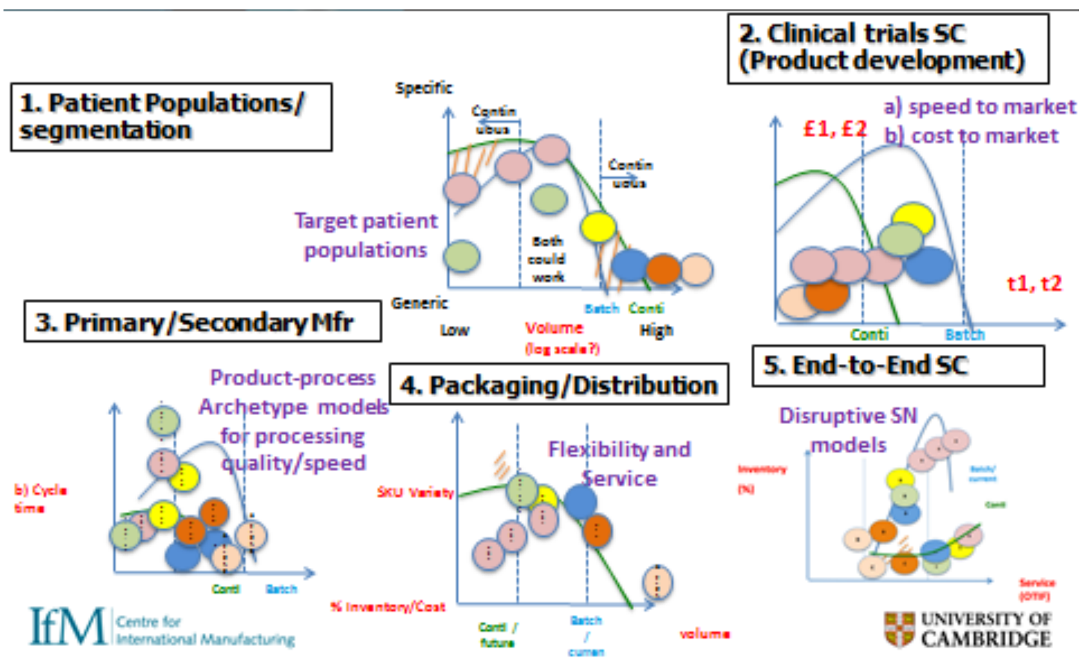
Sub-system and Systems analysis

The research questions being addressed at the sub-systems level for each sub-system were focused on adoption of continuous manufacturing technologies. Example questions that were considered are set out below;

- RQ: *What are the patient populations (volume/variety) incl. unmet needs that are pre-disposed to conti-processing in terms of SC performance*? Factors to be considered
  - 1ry: disease area/patient populations, met/unmet need, volume
  - 2ry: dynamics incl. seasonality/volatility, dose-form, location & sites
  - Outcome: Validating the patient populations concept diagram, qualitatively and quantitatively
- RQ: How does conti optimise overall revenue, lead time ? How does conti reduce investment (and risk) for the target product timeline? Factors to be considered
  - 1ry: speed (t1, t2) and revenue potential, pre-investment, investment risk
  - 2ry: c-t cost, final production cost,
  - Outcome: Defining the opportunity for overall revenue, lead time reduction for target patient populations
- RQ: What are the viable and attractive product-process archetypes and configurations that match target patient populations and manageable product portfolios, and shorten processing cycle times? Factors to be considered
  - 1ry: viability of attractive product-process archetypes exist at required scale (conti-batch mix, intermediates mfr (e.g. batch unstable), substance dose form), plug-and-play instant/rapid changeover process technologies, viable product-process network configurations exist that meet product portfolios
  - 2ry: existing asset base constraints, supplier capabilities?
  - Outcome: viable and attractive product-process archetypes and configurations exist that match target patient populations and manageable product portfolios
- RQ: How to better configure a demand driven pack supply chain that match target patient populations and manageable product portfolios?? Factors to be considered
  - 1ry: in-line primary packing capability, secondary pack customisation, instant/rapid changeovers, reducing lot size (potentially lot sizes of one), mix-tertiary pack capability?, plug-and-play instant/rapid changeover packaging technologies
  - 2ry:, regulatory context and quality assurance
  - Outcome: Minimising ‘lot’ sizes to support niche markets and volume flexibility, more responsive supply chains, massive inventory and waste reduction, risk benefits on demand uncertainty and pack control
- RQ: What are the new supply network and business models that might emerge from conti technologies and processes? Factors to be considered

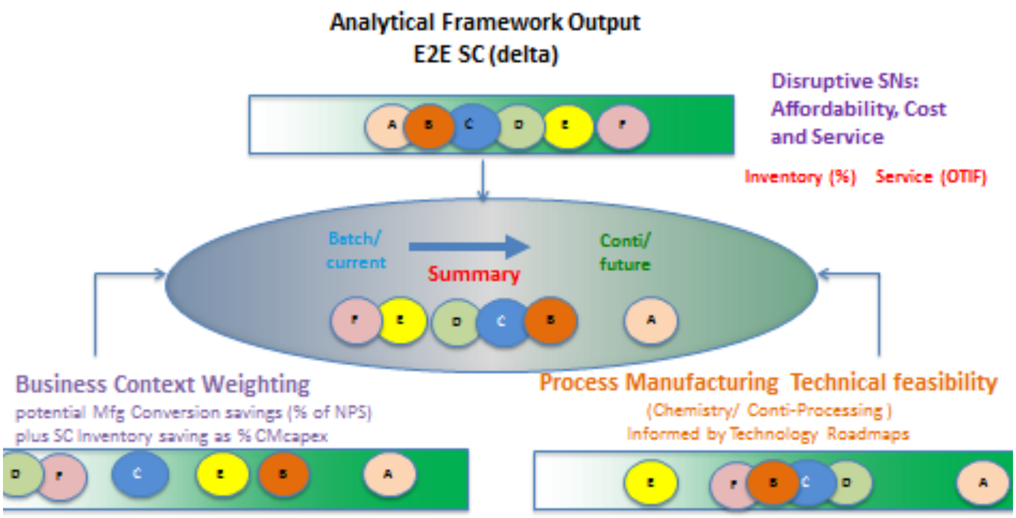
- 1ry: extended supply chain actor motivations understood and aligned, healthcare landscape/ecosystem known in terms of info, material, revenue flows across the product development, and product supply life cycle value chains
- 2ry: disaggregation and reconfiguration of established networks through the interaction of digitisation, information and emerging therapy technologies
- Outcome: New healthcare disruptive supply networks and business models underpinned by conti technologies and processes

The schematic below sets out the results of this analysis identifying the key factors that drive sub-system and total system optimisation, and how these impact each other.



4 Total system analysis – optimising product-process models against business context and technological feasibility

The analytical framework described earlier was then deployed to examine the interactions between the value network sub-systems in Pharma (for example, Clinical, Primary/Secondary Manufacturing, Packaging and Distribution, E2E Supply) in order to inform the selection of continuous manufacturing candidates (therapies, patient populations, product-process models). Initial continuous manufacturing candidate profiles were identified, setting out viable business transformation scenarios informed by the value network analysis, integrating inputs on technology readiness from participating technology experts.



Conclusions

Previous research studies suggest that many complex industrial systems comprise of semi-independent sub-systems that have evolved over extended time periods but have then become part-disconnected, operating as silos of activity with independent governance and coordination mechanisms. In many cases, the regulatory frameworks ‘lock-in’ this structural development.

An approach has been developed based on considering radical reconfiguration opportunities that take a systems perspective rather than traditional optimisation at sub-units of analysis. The approach introduced here helps to reveal reconfiguration opportunities that support the re-integration of these sub-systems by enabling a deeper understanding of the drivers of, and interactions between, the main sub-systems that make up complex, multi-tier value networks.

This approach is explored within the pharmaceutical sector, specifically how continuous processing may benefit a range of new product and patient groups. The preliminary analysis suggests that the methodology can help to reveal reconfiguration opportunities that support re-integration of these sub-systems and enhanced performance.

Future work

The work is part of an on-going research agenda that seeks to develop next iterations of the Pharma value chain. This involves extending the preliminary analysis conducted for selected patient populations and product-process archetypes identified as having attractive business/value propositions and promising technological feasibility. Consideration of the behavioural changes and dynamic capabilities required to make the transformation across the value network will be developed as part of this future activity.

Acknowledgements

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References

Gereffi G, Humphrey J, Sturgeon T (2005) The governance of global value chains. Review of International Political Economy 12:78–104.

Jacobides MG. 2005. Industry change through vertical disintegration: How and why markets emerged in mortgage banking. Academy of Management Journal 48(3): 465-498.

Kaplinsky, R. and Morris M. (2001), "A Handbook for Value Chain Research", prepared for the IDRC, Institute of Development Studies: Sussex

Kogut, B. and Zander, U. (1993), 'Knowledge of the firm and the evolutionary theory of the multinational corporation', Journal of International Business Studies, 24(4), 625–45.

Lambert, D.M. and Cooper, M.C. (2000), "Issues in supply chain management", Industrial Marketing Management, Vol. 29, pp. 65-83.

Lee, H.L. (2002), "Aligning supply chain strategies with product uncertainties", California Management Review, Vol. 44 No. 3, pp. 105-19

Lorentz H, Pichawadee Kittipanya-ngam, Srai JS, 2013. Emerging market characteristics and supply network adjustments in internationalising food supply chains, International Journal of Production Economics

Porter, M. E. (1980). Competitive Strategy: Techniques for Analyzing Industries and Competitors", New York: Free Press Porter, M. E. (1985). Competitive Advantage", New York: Free Press

Srai J.S., Gregory M.J., 2008. A Supply Network Configuration Perspective on International Supply Chain Development. International Journal of Operations Management, vol. 5 (May 2008)) 386-411.

Srai J.S., 2013. Value-chain configurations of emerging country multinationals. In The Competitive advantage of emerging market multinationals, Williamson PJ, et al. Cambridge University Press.

Srai J.S. and Alinaghian LS. 2013. Value chain reconfiguration in highly disaggregated industrial systems: examining the emergence of healthcare diagnostics. Global Strategy Journal, 3: 88-108.

Schilling, M. 2000. Towards and General Modular Systems Theory and its Application to Inter-firm Product Modularity. Acadamy of Management Review. 25:2, 312-334.

Skinner, W. (1969). Manufacturing-missing link in corporate strategy. Harvard Business Review

Sturgeon, T. 2001: How do we define value chains and production networks? Special Working papers series, MIT IPC Globalization Working Paper 00-010

Sturgeon, T. 2002: Modular Production Networks: A New American Model of Industrial Organisation, Industrial and Corporate Change, 11(3): 451-96

Progressing Virtualization of Production - Contributions from Distributed Manufacturing

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Computing miniaturization and smart devices change manufacturing. Virtualizations and atomisation of resources unwrap novel manufacturing principles. Virtualizations of units, processes and resources obey specific laws and have strategic impact on manufacturing with major implications. Mechanisms from distributed manufacturing engaging interacting intelligent manufacturing units and decentralized planning and decision procedures illustrate important effects of the shift of focus towards collaboration and interoperability.

Keywords: Smart units, Concurrency, Information model, Decision cycle, Network management

Introduction

Competition, rising costs and higher prices for resources, combined with stronger regulations of governments enforce activities in manufacturing to revise processes, to track products and objects and take more responsibility for after use and reuse of products and systems. Supply networks become increasingly reliant on solid collaborations, on intermediate suppliers and on contract manufacturers. The challenges, as listed, coincide with newly appearing technology options. Intriguing devices from ICT seem to push manufacturing into a next generation virtualized and computerized world.

Important developments are mainly telecommunication driven and discussed under different chapters, as Internet of things, Ubiquitous Computing, Cyber Physical Systems, Smart Objects or comparable terminology. Subsequent approaches for computerising manufacturing units and processes propagate a number of powerful and fascinating services, ready for implementation. The appearance of novel devices, able to be positioned, to be tracked, to be identified on one hand, also capable to communicate, to act, to negotiate and even to decide on the other seems to take dominating influence on everything that concerns manufacturing. Decentralisation and atomisation of processes, units and procedures and their virtualisations are in trend. Manufacturing research as well as practice should therefore be able to provide to a wider theory base as well as clearly outlined rationalities for the encountered principles and properties.

Some principles that had been found for Distributed Manufacturing[1] now reappear for Manufacturing in total, so the upcoming set ups can be mirrored to the distributed manufacturing experiences and the findings there. As various communities from different disciplines outside of manufacturing are intensively working on new services and devices, the most important recent developments, relevant for manufacturing, are sketched. All virtualisations base on information models, so a structured overview on frequently used models in manufacturing is recalled. To obtain closed and coherent descriptions of networks topological spaces are introduced as a start for further discussion. The space construct, as outlined, reduces down to the essentials on one hand; on the other hand it is powerful enough

[1] Distributed Manufacturing is a manufacturing network whose functionality and performance is independent of the physical distance between the involved systems and system elements. This includes logical and spatial dispersed units which cooperate and communicate over processes and networks on order to achieve manufacturing functions (Kuehnle, 2010).

to capture all relevant aspects of manufacturing. The possibility of smoothly attaching model worlds to the nodes of the space literally imposes interpretations of cyber physical production and smart objects. The resulting set of loosely coupled, autonomously acting manufacturing units are evidently subject to principles and modes of complex structures that are known from advanced mechatronic systems and DM set ups (Kuehnle, 2012) already. In this context, procedures for controlling the behaviour of units and the generalized principle of encapsulation are outlined for generalisation. The final section is devoted to managerial implications. The paper aims at offering a more comprehensive theory base for virtualizing manufacturing. Practitioners should be provided with solid trajectories concerning these rapid developments and expected impacts as input for their decisions and to verify their gut feelings for the next steps in organising processes and in implementing ICT in manufacturing networks.

ICT thrusts with Impact on Manufacturing

Research and developments in the fields of telecommunications, computer science and engineering have shown vast progresses. Miniaturised, smart and multi-functional electronic devices with enormous computation capabilities and with high mobile, ubiquitous, uninterrupted, and embedded capabilities are already in use in daily life (Adelstein et al., 2005). In consequence, ICT is changing the working environment in manufacturing as well. Some important IT developments have been provoking intensive actions and reactions in the manufacturing world, not only on company levels but on national and international levels (Open China ICT, 2012) as well. Considering the fact that telecommunication, software and computer industries involve biggest players with enormous research capacities on this field, more brilliant innovations will be ahead with radical and disruptive consequences for manufacturing. Their potential cannot be ignored by manufacturing companies as these novel ICT achievements are comfortable and efficient on various other sectors; undoubtedly they will irreversibly and broadly find their way into the manufacturing world too.

Cyber physical systems

Some years ago, an object virtualization method has emerged, known as Cyber-Physical System (CPS, also DCPS if distributed) (Sztipanovits 2007; Lee, 2008; Wolf, 2009), meaning the integration of computing systems with physical processes and physical environments. Major motivation behind the notion of CPS is the need to design and produce reliable and sustainable computing systems that work in harmony with their surroundings (Ptolemy, 2013). Components are networked at every scale and computing is deeply embedded into every physical component, possibly even into materials (Sztipanovits et al., 2012; Derler et al., 2012). Exploiting cyber physical systems for manufacturing has brought up the terminology of Cyber Physical Production Systems (CPPS), which is strongly propagated in the national funding scheme Industry 4.0 in Germany. The introduction of CPS into automation is expected to break up the monolithic functional automation pyramid into virtualized distributed networked nodes that are more difficult to handle; therefore machine toolmakers claim urgent need for joint actions (VDI/VDE, 2013). When using CPS, components could adapt themselves automatically to the other components, which inevitably changes the way in which these CPS-enabled components are designed and manufactured. Therefore manufacturers see reasons for totally rethinking industry and industrial production when establishing CPPS to take full advantage of CPS, (VDI/VDE, 2013).

The Internet of things (IoT), Pervasive Computing and Smart Objects

Parallel to CPS (US), computer scientist had come up with the Internet of Things (IoT) in the context of ERA (EU).

CPS and IoT cannot be clearly differentiated since both concepts have been driven forward in parallel, although they have always been closely related (CERP-IoT, 2009). The IoT is considered a part of the future internet and could be defined as a dynamic global network

infrastructure with self-configuring capabilities, where physical and virtual "things" have identities, physical attributes, virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network [2]. IoT is highly relevant to manufacturing. In industry, the "thing" may typically be the product itself, the equipment, the transportation means, etc. It is obvious that developments, too, accelerate the integration of Smart Objects in the Internet. Additionally pervasive computing has migrated from desktops to cell phones, and embedded computing is increasingly integrated into various kinds of objects.
By adding more data to objects, we are witnessing the upcoming of a huge IoT, where every physical object has a unique identity (RFID, RFIT), (Eguchi & Thompson, 2011). We shall experience smart worlds full of smart objects (Kortuem u.a., 2010). A Smart Object (SO) is an autonomous physical/digital object augmented with sensing, processing, and network capabilities[3]. RFID technology is closely linked to SOs. In contrast to RFID tags, SOs carry chunks of application logic that let them make sense of their local situation and interact with human users. Coupled with software agent technology however, RFID can transform everyday objects into smart objects as well (Chan et al., 2012). Smart objects and all the developments around are considered as being highly relevant for manufacturing as RFIDs are already in use.

Ubiquitous Computing (UC), Cloud Computing, Cloud manufacturing (CM), Grid Manufacturing, Cloud Based Distributed Manufacturing and Hybrid Clouds

UC, too, has been further upgrading objects to smart objects, which can provide customers with new services that could not have been imagined before, because of the steady connection between the real-world objects and the intelligence of information systems. UC denotes another vision of a future world of smart objects, i.e. physical items whose physical shape and function is being extended by digital components (Langheinrich et al., 2000). The increasing miniaturization of computer technology results in processors and tiny sensors being integrated into more and more everyday objects, replacing traditional computer input and output media. Instead, people will communicate directly with their clothes, watches, pens, or furniture – and they communicate with each other and with other people's objects (Ferguson, 2002). It is neither a single technology nor a specific functionality, which is behind UC but rather a bundle of functions which together create a new quality of computing (Satyanarayanan, 2002).
Cloud architecture provides users with the ability to utilize the manufacturing capabilities of configurable, virtualized production networks, based on cloud-enabled, federated factories, supported by a set of software-as-a-service applications (Meier et al., 2010). Cloud computing is novel model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (NIST, 2011). A cloud is a type of parallel

[2] Technologies for realizing IoT devices have already been around for years, and have been standardized by the IETF, starting from the lower layers of the stack and moving up. Today, we have IPv6 as a foundation running over links such as those found in mobile networks (2G, 3G and LTE) as well as low power local area sensor networks such as IEEE 802.15.4/6LoWPAN and EPICS. The implementation can be based on multiple agent languages and platforms (JADE, JADEX, LEAP, MAPS) on heterogeneous computing systems (computers, smartphones, sensor nodes).

[3] In 2008, an open group of companies launched the IPSO Alliance to promote the use of Internet Protocol (IP) in networks of "smart objects" http://www.ipv6forum.com/index.php. As different definitions of IoT do currently exist, for manufacturing purposes it is useful to refer to IoT as a loosely coupled, decentralized system of smart objects (SOs), which are autonomous physical/digital objects augmented with sensing/actuating, positioning, processing, and networking capabilities. SOs are able to sense, log, and interpret information generated within themselves and around the neighbouring external world where they are situated, act on their own, cooperate with each other, and exchange information with humans. The development of an IoT, based on SOs raises many issues involving hw/sw system architecture and application development methodology in general; discussions on particular applications in manufacturing are just starting. A few approaches (e.g. FedNet, UbiComp, Smart Products) have already been proposed to support the vision of an SO-based IoT infrastructure.

and distributed system consisting of a collection of interconnected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreements and established through negotiation between the service provider and consumers (Buyya et al. 2008). Virtualisations of resources and fast interconnections open up companies in general and manufacturing areas in particular to new services and services' architecture i.e., cloud hardware-as-a-service (HaaS), cloud software-as-a service (SaaS), cloud platform-as-a-service (PaaS), cloud infrastructure-as-a-service (IaaS). Virtualized computing resources allow "big data" storage and flow, cloud ERPs and Cloud CRMs are already available, online monitoring and positioning of all products and resources enables tracking and fixing issues in real time, allowing companies to instantly improve all attributes of the manufacturing process.
A number of researchers already propagate to specify Cloud Computing into Cloud Manufacturing CM (e.g. Yang, 2010). CM is envisioned as a new mode of networked intelligent manufacturing which is service-oriented, highly efficient and anticipates the development of the concept of Cloud Computing in manufacturing. CM may become a networked manufacturing mode with quickest responses to market demand, enhanced competitiveness and facilitated collaborative manufacturing (Zhang et al., 2010). Furthermore Resource Cloud Encapsulation RCE of soft and hard manufacturing resources and resource sharing are projected as services for further resource virtualization in CM (Ming & Chunyang, 2013).
In IoT and CPS, technologies are already used to access and to connect manufacturing resources. In RCE, all physical manufacturing resources are seen as transferred into logical services; based on complete resource virtualization, RCE technology constructs large-scale virtual manufacturing resource pools that can be used for interacting and feedback control of manufacturing. RCE is supposed to largely reduce the coupling between physical resource and manufacturing application by the transferring physical resources into logical resources and virtual CM services with instant utilization, high agility, high security and high reliability. In addition, resource pooling and virtualization enable even more sophisticated solutions under Cloud-Based Design and Manufacturing (CBDM). It is a type of parallel and distributed system consisting of a collection of inter-connected physical and virtualized service pools of design and manufacturing resources (Wu et al., 2012) possibly leading to new perceptions of product design and manufacturing.
All cloud solutions enable to dynamically adapt in order to satisfy unpredictable or unexpected demand. The manufacturing cloud service can offer rapid scalability at certain levels, such as manufacturing cells, general purpose machine tools, and standardized machine components. Given that the cloud is a huge shared service pool of design and manufacturing resources, it may also be possible for cloud service consumers to find some dedicated tools and equipment for some specific products available in the manufacturing cloud that can satisfy their requirements (Wu et al., 2013).[4]
Public clouds are handled by third parties, and the work of many different clients may be mixed in the factories (virtual), servers, storage systems and other infrastructure in the cloud. End users do not know what other clients works may be carried out in the same factories, even on the same machines. Private clouds are a good choice for companies that need high data protection. Hybrid clouds that combine the models of public and private clouds may be the key to achieving an external supply in scale form and under demand, but these clouds add

[4] Web Services Resource Framework - WSRF - seems to be another closely related work that has been brought forward by the Organization for the Advancement of Structured Information Standards (OASIS). One of the key technologies in these manufacturing grids is how to extract and describe and express the manufacturing grid resources. Manufacturing resource description for manufacturing grid is done via the encapsulation of manufacturing resources in order to provide the grid-enabled services, registration and discover of grid services for the optimal allocation of manufacturing resources and process control. In order to realise the resource sharing and collaboration among the heterogeneous and distributed manufacturing resources, web service resource framework based on resource management and manufacturing resource encapsulation are needed.

the complexity of determining how to allocate tasks and processes across these different environments (Macia-Perez et al., 2012).

Model World of Manufacturing and ICT trajectories

Whenever we talk about interacting, negotiating and communicating objects, we always talk about respective models of these objects performing such activities. Also planning, decision and execution in manufacturing does obviously not regard the units themselves but certain models and attributes of these units that configure and are put into relations. Each step may make use of a number of models interacting, raising the question of how their dependencies and simultaneous actions influence choices, highlight attributes or require certain levels of detail of these models to be involved. The manufacturing network units' interaction structure must be envisioned as an interrelations' structure of specific models, representing these units. Envisioned like this, manufacturing does not just consist of simple units but of objects that encapsulate rich model structures, able to unfold numerous attributes and properties into the attached realm of models.

Manufacturing networks may then be interpreted as specific Hausdorff spaces. The topological nature of Hausdorff spaces allows identifying network units (nodes) and to attach tangent spaces to each one (Kuehnle & Dekkers, 2012). The set-up is rich enough to capture a vast majority of configurations and decision situations occurring in manufacturing networks. This is accomplished by "attaching" tangent spaces carrying adequate models, attributes, relations and aspects assigned to the manufacturing networks' nodes (Fig. 1). Moreover, these virtualisations of manufacturing objects, also called mappings, capture e.g. encapsulations of behaviour, fold and unfold properties, on-off modes of self-organisation. Configurations may be mapped and monitored as well by models, indicators and attributes, and the views are expressed by composite attached models, the reason why all mappings are assumed to be homeomorphous.

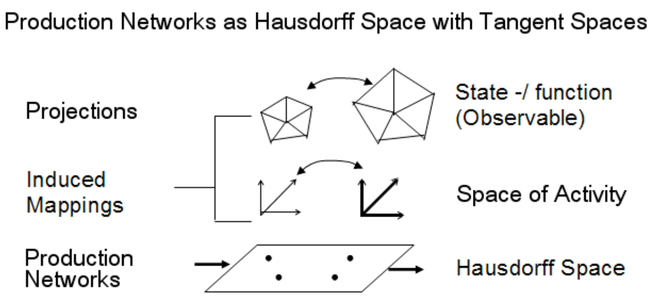

Figure 1: Production Networks' units with attached tangent spaces (models) as mappings of Hausdorff Space nodes according to (Kuehnle, 2006)

In practical terms, the homomorphism postulate stands for compatibility of models of different units. Models of tasks of different units can form a process flow model only and models of machines of different units compose a useful layout only, if the respective units' models are compatible. To be able to do this easily, all involved virtualisations of the units will have to be standardised in some way, so a collection of units represented by attached models is instantly able to link, to interact and to execute important procedures e.g. for manufacturing planning, structuring, operating, linking, improving and deciding.

Models for manufacturing management and -planning

To answer the question about which models are to be attached for manufacturing applications, which properties and attributes ought to be mapped, the chapters of manufacturing systems planning and control history may be recalled. With the sophistication of manufacturing, important abstractions and experiences have been consolidated into a collection of generally recognised models, instruments and tools. With the introduction of computers in manufacturing, many of these models and instruments (or derivates thereof) have been successfully incorporated in standard software e.g. ERP, Cave, DSS or facilities' planners. Manufacturing management generally makes intensive use of these models and model systems for specific problem solving, routine decisions and planning support, for instance for shopfloor planning, adequate models are flow charts, Sankey graphs, DMU/VR based on geometry data of buildings and machines.

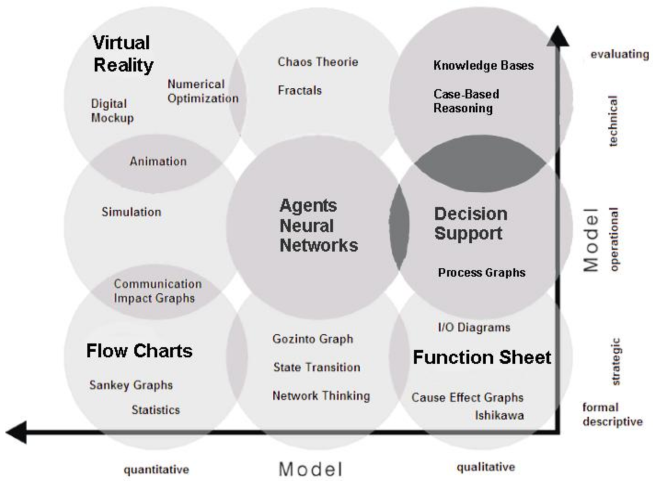

Figure 2: Portfolio of generally used information models for manufacturing planning and decisions, attachable to the network units according to Kuehnle 2012

A structured approach to display important sets of models for manufacturing has been made in the context of concurrent enterprising and collaborative distributed planning, which could be considered as a base for virtualizing manufacturing networks.

ICT use and Manufacturing Models' availabilities

Of course, the application of the models, as described above, depends on the availability of computing power and respective software. Even for the near future it is foreseeable that most smart units in manufacturing will have enough computing power to carry these as an encapsulation. Just to trigger some ideas, the progress in decentralized ICT support with availability of these models for manufacturing processes may be illustrated over the time line and the data volumes involved (Fig. 3).

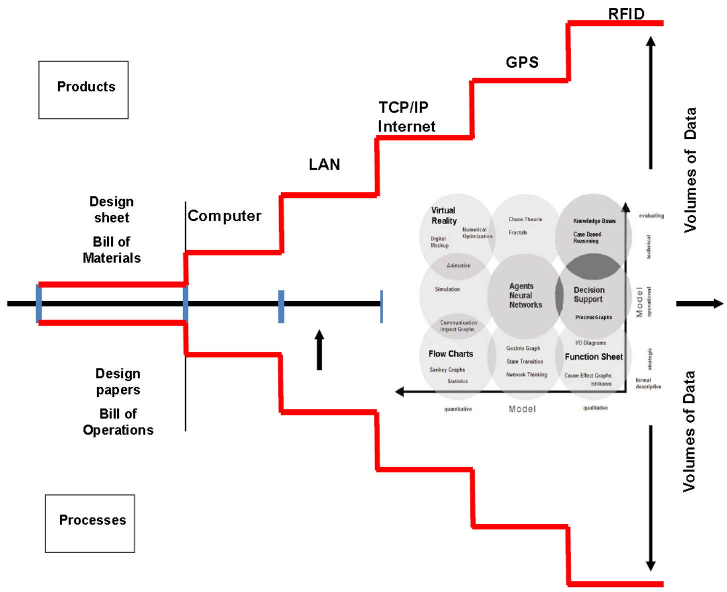

Figure 3: ICT devices and corresponding data volumes and respective model worlds to be implemented, arrayed on a timescale

As one trajectory for future manufacturing it may be kept in mind, that manufacturing units may be imagined as carrying all the models discussed above ready for application to link, to compose, to negotiate and to decide (processed by own computing power or remote). Manufacturing then appears as a set of loosely coupled autonomous smart units, spontaneously forming networks and executing processes; concurrent and evolving planning; negotiating decisions, all by interrelating models. This appearing set up seems to be quite different from what we are accustomed to when describing manufacturing and manufacturing management. Therefore it may be considered worthwhile to take a closer look at this emerging world of smart manufacturing units and the rules of the game there and to search for characteristics and principles.

Principles, Properties and Modes

On a smaller scale, many of the phenomena stated have already been encountered with configurations of distributed manufacturing (Kuehnle, 2010). Seeing all the similarities, the attempt to generalise and widen up important principles that have been identified for loosely coupled manufacturing systems, to the manufacturing networks' level, appears most promising. For start, a list of properties for smart units in manufacturing may be given that support compounding manufacturing processes of networked elements. Most of the capabilities, which smart objects for general use include already, are suitable for manufacturing process set ups, therefore their adaptation is less a question of requirements fulfilment, and it seems to be more a specification matter.

Smart Units' Properties and Requirements

Modularity

For increasing flexibility of operations as well as the ability to be easily reconfigured due to changing conditions, typically modularity is introduced into manufacturing operations and equipment design. Modularity is generally followed by distribution of functionalities, frequently accompanied by physical or/and geographical distribution. The principle of modularity is known and widely used in manufacturing and organisation already.

Heterogeneity

Due to the variety of devices and units engaged, the manufacturing networks are intrinsically heterogeneous. Heterogeneity can occur on various levels and for a number of reasons; on the technical level, heterogeneity comes from different hardware platforms operating systems database management or programming languages; on the conceptual level, heterogeneity originates from differences in understanding and modelling the same real-world phenomena.

Time synchronization

Timekeeping technologies, such as Global Positioning System satellites and the Network Time Protocol provide real-time approximation of Coordinated Universal Time (UTC, world time standard) are used.

Interoperability

Technologies for realizing smart devices have already been around for years, and have been standardized by the IETF, starting from the lower layers of the stack and moving up. Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged (IEEE, 1990). In distributed manufacturing, interoperation abilities are aimed at on all levels, people resources, between enterprises and enterprise units[5].

Scalability

The capability to extend resources in a way that no major changes in structure or application are necessary is generally referred to as scalability. Due to stronger links between cyber objects and real manufacturing units, the term of scalability becomes relevant for manufacturing systems too. For example, the cloud system allows the cloud service consumers to quickly search for and fully utilize resources, such as idle and/or redundant machines and hard tools, in another organization to scale up their manufacturing capacity.

Concurrency Modes and Mechanisms

Recognizing these potentials is surely not exaggerated to postulate the necessity of a complete re-thinking of manufacturing and a thorough revision of every well established and habitually used, so far proven and uncontested, manufacturing setup. It's not only the fact that all solutions have been set up without employing such options and technical possibilities, it is no longer possible to establish factory centred solutions on the base of pure systems thinking, widely ignoring the network nature of manufacturing. Most prominent examples are deeply rooted for example the term of process and supply chain in manufacturing; in reality we work on the base of process and transformation stage networks, which expose process chains ex post as planning and decision results.

Behaviour

Behaviour is the range of actions made by systems, or abstract units, in interaction with other units and the environment. A unit shows its state in indicators (variables, data) and exposes its behaviour through methods (functions) that react to certain events. Process parameters present the behaviour of a unit and its interactions with other objects. Monitoring tools enable the users to specify and to process-level events such as inter process communication, as long as these events are at the correct level of abstraction of the network units, as successfully

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[5] Interoperation may occur between two (or more) entities that are related to one another in one of three ways (ISO 14258) (ISO, 1999): a. *Integrated* b. *Unified* c. *Federated*. Many discussions of interoperation refer to TCP/IP protocols or the OSI/ISO layer description, even if not fully compatible. Gateways allow interconnecting any non-IP-based smart object to the net. However, most networks very quickly migrate to IP as gateways lack flexibility and scalability. IEC TC 65/290/DC identifies degrees of compatibility depending on the quality of communication and application features (Kosanke, 2006).

EPICS (EPICS, 2013) is also wide spread, originating from experimental physics and industrial control that has been used or originally for sophisticated devices in electronic laboratory or measurement centres. The IPSO Alliance included interoperability tests of IPv6 devices over different physical layers. The Smart Object architecture roughly conforms to the Virtual Entity, the Information Model, and the Channel Model set out in the IoT-A Architecture Reference Model (IoT-A ARM) and supports direct interaction between smart sensors, smart gateways, cloud/internet services, and user devices. Interaction uses standard web protocols and formats and is semantically a superset of the CoAP protocol. Interoperability discussions are still going on. It is expected that there will be very comfortable and easy to use standards coming up for connecting any units anywhere and anytime.

applied in DM (Kuehnle, 2010). As a representation of the units' behaviour, Spaces of Activity (SoA) may be described by the units' objectives, the resources and constraints. In consequence, the SoA volume may be identified as the unit's decision space i.e. admitted zone for the units' state (Fig. 4). The unit's behaviour, e.g. expressed by corresponding indicators, gives input for decisions on maintaining the unit's self-organization mode or reducing autonomy and calling for external interference. In cases of a unit's inability to cope with the objectives or the changes in the environment, network "order parameters" may gain influence on the units' activities ((self) reproduction, (self) destruction, (self) structuring).

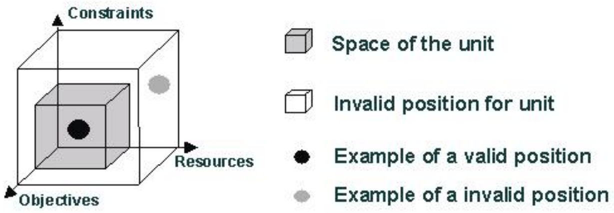

Figure 4: Space of Activity (SoA) as mapping of network node for monitoring the behaviour of the unit by relevant indicators and observable

This "biologically" inspired manufacturing approach addresses challenges in complex (unpredictable) manufacturing environments tackling aspects of self-organization, learning, evolution and adaptation (Ueda et al., 2000). They easily adapt to unforeseen changes in the manufacturing environment, and achieve global behaviour through interaction among units (Bongard, 2009). Applied for manufacturing network decisions, such behaviour thinking supports levelled manufacturing network adaptation procedures.

Parallelism

An optimum base for collaborating using least resources and time is to do substantial steps towards parallelism of all actions and operations. Parallelism aims at reducing execution time or improving throughput. Adding parallelism to an event driven view requires reasoning about all possible chains of transitions to determine events that might interfere with others. Parallelism for mobile applications uses operation time and requires sophisticated algorithms since it is not sufficient to run just a few services in parallel. Mobile systems are power constrained but improved wireless connectivity enables shifting computations to servers or the cloud. Leading experts state that, generally, parallel systems can be expected supporting task parallelism and data parallelism, both essential for decentralised and distributed manufacturing applications. Eventually each node of a task can have multiple implementations that target different architecture (Cantanzaro et al., 2011). For manufacturing applications this allows taking full advantage of the task parallelism on one hand and running independent operations in parallel on the other. Parallelism will revise process planning, for example, by building sequences from independent sub-sequences. For parallelism of operations in manufacturing, industrial networks will strongly rely upon dynamic forms of communication and coordination that handle non-predictable situations by self-adaptiveness and self organization.

Iteration

Developing configuration options and decide about favourable configurations is a highly iterative process and not a straight-line journey. Loops back are possible, as factory and network capabilities identified and may not fit or others may give rise to potential new business opportunities. The 'Iteration' mode emphasises the fact that there is an inherent, evolving nature to structuring. Iteration results in changes that must propagate through the structure's stages, requiring continuous process rework. Within simple settings of collocated operations, the challenge of managing can still be achieved by conventional planning systems and respective intra-organisational decision mechanisms. For networks, management becomes much more complicated, as the involved units and their roles are not stable, but evolve dynamically. However precisely these properties enormously increase a companies' adaptabilities and strongly amplify differentiations and uniqueness. This means continuous restructurings and adaptations for manufacturing networks as well. For the decisions on structuring, re-linking, or breaking up connections in manufacturing networks, iterative procedures develop both system structure models and map behaviours onto structures vice versa, ensure the manufacturing networks robustness, their stability against uncertainties, operator mistakes, or imperfections in physical and/or cyber components. Since integration into processes must be orchestrated in order to achieve suitable performance behaviours, it is necessary to ensure the expected alignment with respect to the fit degrees, similar KPI or (estimated values of) key alignment indicators (KAI), (Piedade et al., 2012).

Encapsulation

In general, encapsulation is the inclusion of one thing within another thing so the included thing is not apparent. In DM, encapsulation is concerned with the possible encapsulations of abstractions of units (e.g. models or task descriptions) and transformations (e.g. processes) (Kuehnle, 2010). The Encapsulation mode enables to build networks and processes by combining elements for creating new processes and units or for atomising units to obtain elements. Self-similarity and compositionality of a unit or a process is a direct consequence of unit- or task encapsulation and provides the basis for constructing networks from components (Lau & Faris, 2007). The models of a unit are accessible through interactions at the interfaces supported by the models. The model element may be seen as based on connectors (links) to construct and compose units. In the tangent space projection, there are two kinds of elements: (i) unit models, and (ii) connectors.
The units are loosely coupled and their control is originated and encapsulated by connectors, which is used to define and coordinate the control for a set of components (element or composite). Indeed, the hierarchical nature of the connectors means that composite units are self-similar to their sub-components; this property also provides the basis for hierarchical composition. Each unit model may additionally encapsulate more models and methods.
In a composite, encapsulations in the sub- units are preserved. As a result, encapsulation is propagated in compositions of newly constructed components (units are self-similar) and is also closely related to components' reuse.
Encapulated models of units and connectors, may arbitrarily be compressed/broken down resp. fold/unfold (Fig. 5). For instance a critical behaviour of a unit on a lower level may have to be compensated on a more aggregated network level or even at the configuration level of the total manufacturing network.

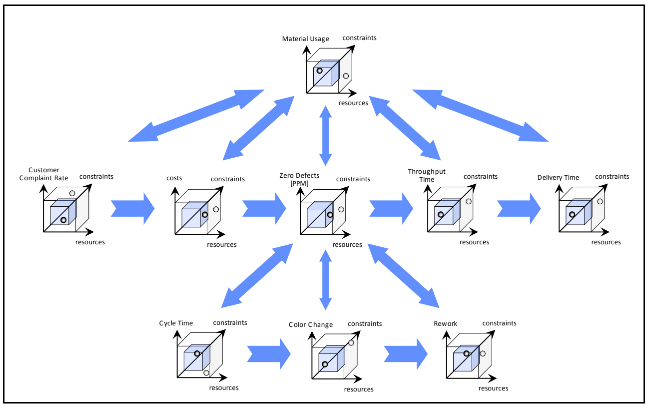

Figure 5: Breakdown (unfolding) of encapsulated behaviour models including criticality spaces into required Levels of Detail

Arising criticalities are to be negotiated and harmonized with other units' objectives and resources. A unit's behaviour may generally result in decisions on maintaining the self-organization mode, reducing or removing the autonomy and calling for network interference along the subsequent decision cycle.

Strategy and Objectives:

The network gets vision, mission and network draft that are later detailed to design and operation. The network strategy has to support the idea that in order to truly align the structure with business requirements, units must be free to negotiate and to choose the solutions that best meet their unique needs.

Monitoring and Analysis:
This stage tracks the execution of the manufacturing processes. It executes by detecting/ sensing the current state of the business and operational manufacturing environment, by monitoring the manufacturing-related business processes for determining if the manufacturing units' behaviours are acceptable (e.g., concerning economic performance), for capturing (unexpected) events and continuously informing on the current situation (e.g., desired, undesired and unexpected events). Activities that constantly update the units' potentials, capabilities or availabilities or that check the network for underperforming units and that notify the network in cases of outages or other alarms, recognised by units' criticalities. Structures, mechanisms and outputs are studied, compared and rated. These analyses may be driven down to sub or sub-sub levels where resource configurations and their contributions to the objectives as well as the SoAs structures (incl. the criticality settings) are broken down.
In cases of less severe criticalities, improvements or objectives' alignments are initiated. Severe criticalities will provoke networks' adaptations or reconfigurations.

Network design

The network is be configured to meet customer requirements best. Partners, units and other actors are identified and linked to a network structure. Processes have to be linked and assigned to responsibilities.

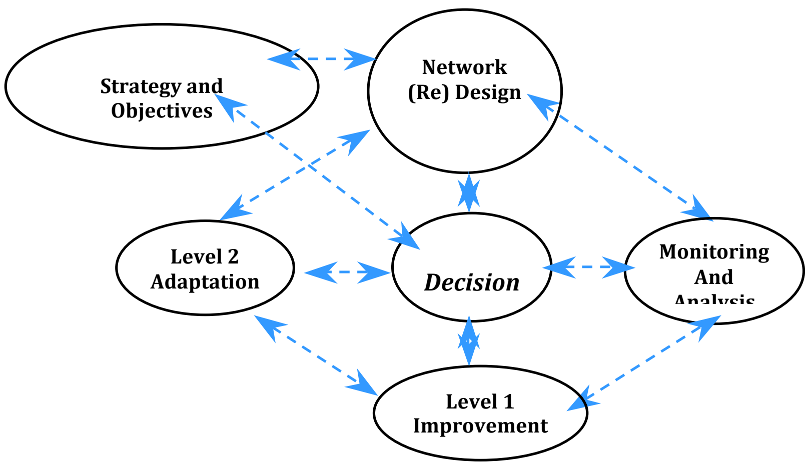

Figure 6: Revolving decision cycle procedure of levelled interventions in Manufacturing for gradual continuous configuration

The strategy elements may be broken down to the decisive factors and the respective indicators that cover all key areas of the networks. They may result in relations of sub objectives and/or aggregated objectives' systems.

Decision:

The decision phase marks the point where the necessary initiatives are taken in order to support the networks evolution into the intended direction. All decisions of importance may be taken, revised, improved or repeatedly cancelled within this cyclic procedure (Fig. 6) i.e. previous program strategy, network configuration, make/buy decision, site decision, process/technology/equipment decisions, etc. are revisited regularly. History and time (complexity attributes) might hinder to execute the resulting decisions immediately. Structures might exist that cannot be instantly eliminated or the building of new competencies will take some time. For the modelling of the network it is therefore recommended to maintain other models (structure simulator) beside the model of the given actual network. These models should provide for "what if" evaluations and simulated comparisons of indicators that make visible, to what extend the actual configuration has "suboptimal" effects on the results.

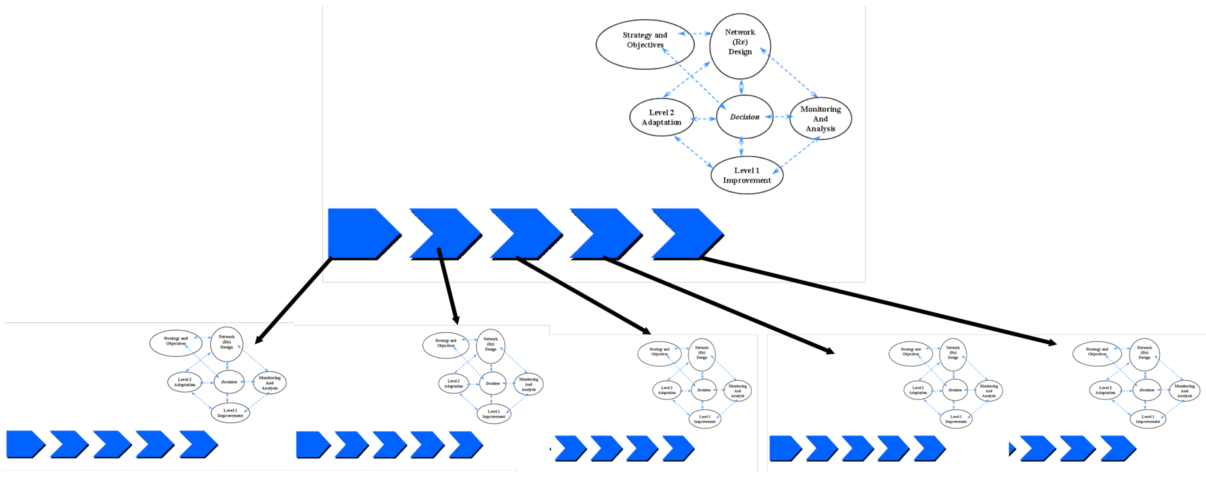

Figure 7: Meshed decision cycles including encapsulated models and instruments to negotiate and decide on manufacturing networks' process fulfilment on several levels of detail according to distributed manufacturing/properties

Fig. 7 illustrates the self-similarity of composite components in a decision network involving the decision cycle as described. Most importantly, every composite component is similar to all sub-components. This means that composition is done in a hierarchical manner. Furthermore, each composition preserves encapsulation. The topological nature ensures that the hierarchical structure of the process is enforced and the encapsulation enforces additional rules to ensure the overall process optimum. A unit component encapsulates all necessary models and procedures. A composite component also encapsulates computation and control (Lau & Fais, 2007). For decentralized decision making based on network business models special logics, algorithms and methods for integration and management seem to be necessary. This concerns the matching of partners as well as the temporary collocation of operations in manufacturing networks. On this basis, all units' behaviour as well as all interrelations may be optimised and planning procedures and logic for the meshed control of configurations, containing processes and resources in networked manufacturing structures, may be established.

Emergence
Emergence focuses on the arising of new patterns, structures and characteristics of networks that are neither really predictable nor fully deductible from antecedent states, events or conditions. DM configurations are ideally envisioned as emergent. Generally, emerging set-ups are characterised as dynamical, meaning they arise over time, as coherent, meaning show somehow enduring integration and occasionally as ostensive, meaning they appear during a set up evolves. In the smart world as outlined, manufacturing processes may therefore be seen as emergent items as well, corresponding to the term emergence precisely in this sense. Complexity science has means to express links and dynamics of interconnectivity, (or what in complexity discourse is termed "emergence"; arising of unforeseen new structures with unexpected new properties (Goldstein, 1999). In Fig. 7 the process chain emerges as a result of the interactions between units. There is no ultimate configuration solution beyond continuous adaptation and restructuring. To say that process chains emerge, however, does not mean to abandon overall planning. Rather than deriving outcomes by rigid adherence to preconceived strategies, the key for ensuring good solutions is to focus on creating effective rules for interactions. These rules ensure alignments among participants that increase the likelihood of favourable emergent network configuration leading to the objectives fulfilments aimed at.

Conclusions and Implications
What definitely follows for industrial practice is that non-hierarchical views of manufacturing will fully establish. Iterative concepts of planning and control will replace central, sequential, rhythmic and time sliced procedures by event-driven parallel distributed evolving logics. Manufacturing will introduce and apply new types of methods and tools, supporting linkage and reconfiguration as well as high level plug & produce, plug & participate and concurrent work skills.

Any decisions on implementation of smart units in manufacturing as well as virtual resources as services are elements of a company's core strategy and cannot be delegated to IT experts or service providers. The services required by manufacturing differ from general services. The main points, which highlight manufacturing, are interaction ability; powerful functionality (manufacturers will want to streamline business processes and to optimize inventory), real-time ability and Multi Corporation set up.

More standards on all levels will be defined, most likely on international level and done by institutions outside of manufacturing. For implementation decisions, it's rather a matter of choosing and evaluating than developing own standards or engaging in standardisation organisations. It is always worthwhile to keep an eye on rapidly spreading devices of telecommunication and respective freeware for general use that could eventually establish irresistible quasi- or de facto standards. Manufacturing near associations ought to provide recommendations which existing or upcoming standards should be considered.

Many virtualization instruments address manufacturing main processes, hence key productivity issues. The use of resources along these models will translate into lower costs for all involved units. Early adopters of such novel distributed manufacturing options might immediately set so far unseen KPI benchmarks and cause competition pressure. Specialization of manufacturers using complex and expensive machinery or factories to develop certain products or sub-products for other manufacturers is facilitated.

Moreover these systems might instantly demonstrate drastic changes in the forms of manufacturing or manufactured products and, especially, could initiate novel business models synthesising new services and new products. Business model development should focus on the research questions (Wu et al., 2013): Why would those involved in this business model choose a smart operating environment over a traditional manufacturing environment? How will equity be assured when value is delivered as a result of shared-interest, multiple-party work? How should IP be handled in collaborative environments?

Especially, Cloud Manufacturing allows easy integration of applications and processes both within an organization and between different organizations that wish to collaborate.
However, some of the greatest concerns are security problems, loss of control (infrastructure, services, and management), technology, difficulty in migrating to other platforms, and loss of reliability. Companies may feel most attracted to the hybrid cloud, an option that might be reserved for applications, which do not require any synchronization or highly specialized or expensive equipment. Initially, hybrid solutions with large portions of proper company implementations are expected.
The development will challenge HR policies. If comparisons to mechatronics and distributed manufacturing hold, there will be mainly high/ICT skilled experts around in these virtualized manufacturing areas. General use of smart services should be sensitive to potential cultural and organizational differences in users' motivation to participate. Collaboration is not always considered appropriate and reasonable across cultures. Control beliefs should be managed by informing and empowering users. An abort button or a similar type of "emergency feature" to disconnect the access of the provider on the user's smart object is relatively easy to implement. Another major managerial implication is that firms should train and provide general guidance to implementations, although not all are front-line employees in a traditional sense, in order to improve their social interaction skills in this technology-mediated service setting. It is important to understand that the introduction of smart interactive services substantially changes the way providers, manufacturers and customers interact (Wuenderlich et al., 2011).
Apart from the possible criticism for its novelty, there is an open controversy with this kind of manufacturing virtualization and all similar approaches, in which IT has a starring role. Although my contributions always try to cover the social informal organizational aspects with at least the same priority as information technology aspects, recent developments and events in manufacturing virtualization give arguments to underpin IT so far. In the near future, however, it is very likely that we shall experience the follow-up rebound in organizations and on the employees' levels with striking effects there. Like a number of times before in manufacturing history, ICT just seems to make the pace. After saturation, especially the exaggerations strike back and will push organizations and collaborations on all levels. However, the actual virtualization wave in manufacturing is, despite of obvious gaps and high risks, unstoppable, because the advantages of these technologies are evident and their benefits are indispensable for manufacturing.

References

Adelstein, F., Gupta, S. K. S., Richard, G. G., Schwiebert, L. (2005), *Fundamentals of Mobile and Pervasive Computing*, McGraw-Hill

Bongard, J. (2009), Biologically Inspired Computing, *IEEE Computer*, April 2009, pp 95-98

Buyya, R., Yeo, C.S., & Venugopal, S. (2008), Market oriented cloud computing: vision, hype, and reality for delivering it services as computing utilities, *CoRR*.

Catanzaro, B., Fox, A., Keutzer, K., Patterson, D., Yiing Su, B., Snir, M., Olukotun, K., Hanrahan, P., Chafi, H. (2011), *Ubiquitous Parallel Computing from Berkeley, Illinois and Stanford*, White Paper

CERP-IoT (2009), *Internet of Things Strategic Research Roadmap* 15 SEPTEMBER, 2009, CERP-IoT, SRA Information Desk European Commission - Information Society and Media DG

Chan, C., Chow, H., Siu, W., Hung Lam Ng, Chu, T., Chan, H. (2012), *A Multi-Agent-based RFID Framework for Smart-object Applications* IMECS, 2012, Hongkong

Derler, P., Lee, E. A., Sangiovanni-Vincentelli, A. (2012), *Modeling Cyber-Physical Systems*, Proceedings of the IEEE (special issue on CPS, Ptolemy Project), 100(1):13-28, January 2012

Eguchi, A., Thompson, C. (2011), Smart Objects In A Virtual World, *International Journal of Computer Information Systems and Industrial Management Applications.* ISSN 2150-7988 Volume 3 (2011)

EPICS (2013), http://www.aps.anl.gov/epics/, last retrieved July 15th 2013

Ferguson, G.T. (2002), Have Your Objects Call My Objects, *Harvard Business Review*, 80 (6), 138–144

Goldstein, J. (1999), Emergence as a Construct: History and Issues, *Emergence: Complexity and Organization* **1** (1) pp49–72

IEEE (1990), IEEE (Institute of Electrical and Electronics Engineers): Standard Computer Dictionary - A Compilation of IEEE Standard Computer Glossaries

ISO (1999), ISO 14258, Industrial automation systems and integration – Concepts and rules for enterprise models, *ISO TC 184 SC5*

Kortuem, G., Kawsar, F., Fitton, D., Sundramoorthy, V. (2010), Smart Objects as Building Blocks for the Internet of Things, *IEEE Internet Computing*, vol. 14, no. 1, Jan./Feb. 2010, pp. 44-51.

Kosanke, K. (2006), *Interoperability of Enterprise Software and Applications*, in: Konstantas et al (Eds.), Springer 2006

Kuehnle, H. (2006), *A model system approach to distributed manufacturing*, Proceedings of CamSIM 2006, Managing Global Manufacturing and Supply Networks, Cambridge

Kuehnle, H. (2010) (Ed.), Distributed Manufacturing – Paradigms, Concepts, Solutions and Examples, *Springer*, London

Kuehnle, H. (2012), Towards Production Network (PN) Theory: Contributions from Systems of Models, Concurrent Enterprising and Distributed Manufacturing, *International Journal of E-Business Development*, 2(2), 53–61

Kuehnle, H. Dekkers, R. (2012); Some thoughts on Interdisciplinarity in Collaborative Networks' Research and Manufacturing Sciences, *Journal of Manufacturing Technology Management, Emerald,* Bd. 23, 2012, 8, pp961-975

Langheinrich, M., Mattern, F., Römer, K., Vogt, H. (2000). First Steps Towards an Event-Based Infrastructure for Smart Things. *Ubiquitous Computing Workshop (PACT 2000)*, Philadelphia

Lau, K.-K., Faris, M. (2007), Data Encapsulation in Software Components, *in: H.W. Schmidt et al. (Eds.), CBSE 2007, LNCS* 4608, pp. 1–16, Springer Berlin

Lee, E. A. (2008), Cyber physical systems: Design challenges, *In: ISORC '08, Proceedings of the 11th IEEE Symposium on Object Oriented Real-Time Distributed Computing, IEEE Computer Society*, Washington, DC, USA, pp363–369

Macia-Perez, F., Berna-Martinez, J-V., Marcos-Jorquera, D., Lorenzo-Fonseca, I., Ferrandiz-Colmeiro, A. (2012), A New Paradigm: Cloud Agile Manufacturing, *International Journal of Advanced Science and Technology*, Vol. 45, August, 2012, p.47

Meier, M., Seidelmann, J., Mezgár, I. (2010), *ManuCloud: The next-generation manufacturing as a service environment,* European Research Consortium for Informatics and Mathematics News, 2010

Ming, Z., Chunyang, H. (2013), Research and realization of Resource Cloud Encapsulation in Cloud Manufacturing, *IJCSI International Journal of Computer Science Issues*, Vol. 10, Issue 1, No 3, January 2013

NIST (2011), *NIST cloud computing reference architecture*, Special Publication 500-292

OASIS reports, http://docs.oasis-open.org/wsrf/wsrf-ws_resource-1.2-spec-os.pdf

Open China ICT (2013), European Commission, Document Number D2.1-European Roadmap Survey, draft

Piedade R. F., Azevedo, A., Almeida, A., (2012), Alignment prediction in collaborative networks, *Journal of Manufacturing Technology Management*, Vol. 23 Iss: 8, pp.1038 - 1056

Ptolemy (2013), http://CyberPhysicalSystems.org/CPSConceptMap.xml

Satyanarayanan, M. (2002), A Catalyst for Mobile and Ubiquitous Computing. *IEEE Pervasive Computing*, 1 (1), pp2–5

Sztipanovits, J. (2007), *Composition of cyber-physical systems In: Engineering of Computer-Based Systems*, ECBS '07, 14th Annual IEEE International Conference and Workshops, pp3 –6

Sztipanovits, J., Koutsoukos, X., Karsai, G., Kottenstette, N., Antsaklis, P., Gupta, V., Goodwine, B., Baras, J., Wang, S. (2012), *Toward a Science of Cyber–Physical System Integration,* Proceedings of the IEEE, Vol. 100, IEEE No. 1

Ueda, K., Hatono, I., Fujii, N., Vaario, J. (2000), Reinforcement learning approaches to biological manufacturing systems, *CIRP Annals – Manufacturing Technology*, Vol. 49, No 1, 2000, pp 343-346

VDI/VDE (2013), Thesen und Handlungsfelder, Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation, *Verein Deutscher Ingenieure e.V. VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA)*, April 2013

Wolf, W. (2009), Cyber-physical systems, *Computer 42(3),* pp88 –89

Wu, D., Greer, M-J., Rosen, D. W., Schaefer, D. (2013), *Review Cloud manufacturing: Strategic vision and state-of-the-art,* Journal of Manufacturing Systems (in press)

Wu, D., Lane J.T., Rosen, D.W., Schaefer, D. (2012), Towards a cloud-based design and manufacturing paradigm: Looking backward, looking forward, *Proceedings of the ASME 2012 International Design Engineering Technical Conference & Computers and Information in Engineering Conference IDETC/CIE* 2012 August 12-15, 2012, Chicago, Illinois, USA

Wuenderlich, N-V., v. Wangenheim, F., Bitner, M.J. (2011), High Tech and High Touch: A Framework for Understanding User Attitudes and Behaviors Related to Smart Interactive Services, *Journal of Service Research,* SAGE Publications

Yang, H. Ch. (2010), Cloud manufacturing is a manufacturing service, *China Manufacturing Information,* No.2, 2010, pp.22-23.

Zhang, L., Luo, Y., Tao, F., Ren, L., Guo, H., (2010), Key technologies for the construction of manufacturing cloud, *Computer Integrated Manufacturing Systems,* Vol. 16, No. 11, 2010, pp. 2510-2520.

Characterising and Designing Last-Mile Distribution - A B2C Systems Typology

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Abstract: The booming of internet based commerce has resulted in many innovative options appearing in the distribution element of the supply chain, which is becoming a point that requires attention in terms of strategic design. We note that the existing LM typology, which forms the basis for LM strategic design, is typically limited and fails to advise on system design. Thus, given the broader supply network theories and typology design theories, and exploring some newly reported cases, we updated the existing typology and developed a new version of analytical framework from the operational and inter-organisational perspectives, with a view to aiding the effective design of such systems.

Key Words: B2C Distribution, Characterisation, Design, Typology

Background

The rising of internet based commerce has resulted in myriads options appearing in the distribution element of the supply chain, which is becoming a point that requires attention in terms of strategic design. We note that the existing B2C distribution typology, which forms the basis for B2C distribution strategic design, is limited and fails to meet broad standard.

Thus, given the typology design theories, and by re-visiting and integrating the existing works of B2C distribution typologists, we propose a new version of typology relating to B2C distribution.

1. Selected Research on Typology of B2C Distribution

According to an enquiry into B2C distribution-related publication database we have identified two pieces of work having an explicit focus on typology of B2C distribution systems, namely Chopra et al. (2007) and Boyer et al. (2005). We recognise the merit of the schemes based on which the two typologies were created, and aim at drawing a more comprehensive and adapted version following the previous paradigm.

2. Research Gaps Identified

The authors of those reviewed supplied typological systems of different kinds. However, in order to make further theoretical advancement, we argue that these typological systems ought to be re-organised on three counts. First, the pieces failed to formalise themselves to be standard typological jobs, preventing us from making comparison unit by unit. Second, there was little evidence available from these pieces as to why the typologies should be established in such ways. Third, the typologies should updated to include recent innovations. The next three sub-sections elaborate each of these assertions.

3. Standardising the Existing Typologies

3.1 Typological Essentials

Typologies permit the co-existence of both similarities and differences, as well as encourage comparisons across these similar and different types. Prior to classifying organisations into types one needs a criterion or certain criteria serving as the sources, which we term as *typological character*. Crownson (1970) and McKelvey (1982) defined that a character (also referred as an attribute, variable, characteristic, parameter, or dimension) is essentially any feature by which an individual can be compared against another; it also allows both similarities and differences between individuals to be measured.

What associates with each typological character is *typological state*. The term is sourced from Sneath and Sokal (1973) when describing the typological character. They denoted that the character is any attribute by which an individual may be measured that has two or more states that cannot be further subdivided within the study at hand, except for the purposes of data coding. In other words, the typological state is the outcome demonstrated by each classified type when measured against the given typological character. Every typological character should of course have two or more states, as there are two or more classified types.

3.2 Standardisation Procedures

In this section, we exercise the effort of standardising the two typologies by framing them into the two typological essentials. This is done through a discourse enquiry into original text which used by the authors to depict the intended typologies (although neither of them have explicitly regarded their works as being typological). We extract the key information deemed to be of making typological sense, and subsequently reconstruct them in the format of typological states, which, in group, are finally summarised into typological characters. We must stress that, in this stage, we stick to as much the original languages as possible so as not to intervene the underlying meanings intended by the writers.

3.3 Standardisation of Chopra (2007)'s Work

Chopra (2007) proposed a number of decision areas which should considered when designing a distribution network:

[…] [a] *1. Will product be delivered to the customer location or picked up from a prearranged site?* [b] *2. Will product flow through an intermediary (or* [c] *intermediate location)?* (P85)

These decision areas fall in the category of typological state, although some "states" have been omitted in the original article.

He continued to classify the distribution network into six types, namely:

[d] *Manufacturer storage with direct shipping;*
[e] *Manufacturer storage with direct shipping and in-transit merge;*
[f] *Distributor storage with package carrier delivery;*
[g] *Distributor storage with last mile delivery;*
[h] *Manufacturer/distributor storage with customer pickup;*

[i]   *Retail storage with customer pickup.* (P85)

We note that the types were named in a way that can demonstrate their intrinsic characters. To illustrate, all the six types unilaterally involve one 'storage' dimension, but the actual manifestations relating to the dimension may differ, e.g. in type [d], storage function is carried out by manufacturer whereas in type [f] and [i], the same function is performed by distributor and retailer respectively. Table 1 presents them in a structured fashion with the omitted items added.

Table 1 Standardisation of Chopra (2007)'s Work

Reference Point	Extracted and Grouped Typological States	Description of Potential Typological Character
a	Product is delivered to the customer location	The point to which product is delivered
	Product is picked up from a prearranged site	
b	Product flows through an intermediary	The intermediary organisation through which product flows
	*Product does not flow through an intermediary	
c	Product flows through an intermediate location	The intermediary location through which product flows
	*Product does not flow through an intermediate location	
d,e,h	Product is stored with manufacturer	The point with which product is stored
f,g	Product is stored with distributor	
i	Product is stored with retailer	

* Underlined contents are the additional states which were omitted in the original article.

3.4 Standardisation of Boyer (2005)'s work

Boyer (2005) maintained that:

There are two decisions associated with extending the supply chain. [j] *First, order fulfillment, or the picking of items for consumer orders, can be accomplished either in existing stores or in a centralised distribution center(s)* […] [k] *Second, delivery to the end consumer can be direct, as in delivery to the consumer's home, or indirect, wherein the consumer is required to pick up her order, or* [l] *a third-party provider such as Federal Express or UPS provides the deliveries.* (P18)

It is clear that this statement also involves the descriptions of some characters and their corresponding states. We replicate the same process as what we did with Chopra (2007)'s work.

Table 2 structures Boyer (2005)'s typology using the two typological essentials:

Table 2 Standardisation of Boyer (2005)'s work

Reference Point	Extracted and Grouped Typological States	Description of Potential Typological Character
j	Order is fulfilled in existing stores	The point in which order is fulfilled
	Order is fulfilled in a centralised distribution center(s)	
k	Order is delivered to the consumer's home	The point to which order is delivered
	Order is picked up by consumer	
l	Order is delivered by a third-party provider	The organisation by which order is delivered

3.5 Integration of the Works

As was noted, some characters and states from different statements appear to be overlapped. We merge the analogous elements to generate a parsimonious listing of typological essentials in the context of B2C distribution. The process is presented in table 3:

Table 3 Integration of the Works of Chopra (2007) and Boyer (2005)

Source	Description of Typological Character Grouped from the	Branding of Emerging Typological	Branding of Emerging Typological States

	Two Sources	Characters	
Chopra (2007)	The point to which product is delivered	Order receipt point	Customer location
Boyer (2005)	The point to which order is delivered		Prearranged site
Chopra (2007)	The intermediary organisation through which product flows	Order carrier	Third-party provider
Boyer (2005)	The organisation by which order is delivered		
Chopra (2007)	The intermediary location through which product flows	Order intermediary point	Distribution center
Boyer (2005)	The point in which order is fulfilled	Order fulfillment point	Existing stores
			Distribution center
			Manufacturer

4. Generalising Typological Essentials

4.1 A Typology of Emerging Typological Characters

It has brought to our attention that the four emerging typological characters are actually interlinked. Table 4 shows a typology of the typological characters:

Table 4

Type	Branded Typological Characters	Commonality
Type I	Order receipt point	Relating to network nodes
	Order carrier	
	Order intermediary point	
Type II	Order fulfillment point	Relating to network partner roles

4.2 Relationship between the Typological Characters and States

We wish to draw a clue as to how the typological characters and states are interlinked to assist identification of further typological elements. It is found (1) that the type I typological arrangement aims at connecting distribution procedural steps, e.g. order fulfillment, with supply chain constituency, e.g. retailer; (2) that the type II typological arrangement seeks to draw a link between distribution procedural step, e.g. order fulfillment and ownership of the handling body, e.g. third-party provider.

4.3 Adjustment of the State of "a prearranged site"

Applying the logic stated in section 6.2 we locate the only "state" that falls outside the pattern: a prearranged site. Actually from Chopra (2007)'s point of view, the prearranged site can include retailers and other facilities; Here we brand other facilities bridging upper stream supply chain with customer as "facilitator", and we propose that facilitator forms part of supply chain constituency and differs from retailer. Both retailer and facilitator can become order receipt point.

5. Capturing Recent Innovations

5.1 Case Studied

We select two innovative practices to expand the current collection. Their nature is presented in table 5.

Table 5 A List of Case Studied and Their Nature

Case No.	Company Name	Nature of the Company Studied
1	Home Plus	Grocer
2	Abby Couriers	Delivery facilitator
3	Parcel Motel	Delivery facilitator

5.2 Presentation of Case 1

Case 1 has a virtual store allowing customers to place order via scanning the barcode from a board virtually displaying goods the same as what customers can get from normal channels.

Case 1 gives a real-life example that another distribution procedural step, namely order placement point, can vary from customer's location to retailer, as shown below:

Table 6 Order Placement Point as a Typological Character

Typological Character	Corresponding State	Case Evidence
Order Placement Point	Retailer	Home Plus
	Customer	All other cases

5.3 Presentation of Case 2 and 3

Case 2 and 3 mediates between the order carrier and customer, taking reception of the goods on behalf of the customer and subsequently arrange timely delivery with the customer. Both cases suggests the inter-organisational structure in table 7, and table extends the existing typological states based on the finding from case 2 and 3.

6. Outcome

Table 9 summarises the new typological arrangement proposed in this paper:

7. Conclusion

In this paper, we applied and integrated the strategic management concepts into B2C distribution system, and developed a framework for designing such systems. We included the latest innovations, e.g. virtual supermarket and facilitated delivery, into our framework to devise an extensive typology characterised by the typological characters and states. This defines a set of operational and strategic factors that will enable the effectiveness of B2C distribution system designing.

Reference

Boyer, Kenneth K., Markham T. Frohlich, and G. Tomas M. Hult. *Extending the supply chain: How cutting-edge companies bridge the critical last mile into customers' homes*. Amacom, 2005.

Chopra, S., & Meindl, P. (2007). *Supply chain management. Strategy, planning & operation*. Gabler.

Crowson, R. A. (1970). *Classification and biology.* New York: Atherton Press.

McKelvey, B. (1982). *Organizational systematics: Taxonomy, evolution, classification.* Berkeley: University of California Press.

Sneath, P. H. A., & Sokal, R. R. (1973). *Numerical taxonomy: The principles and practice of numerical classification.* San Francisco: Freeman.

Table 7 Inter-organisational Structure of Case 2 and 3

<table>
<tr><td colspan="2" rowspan="2"></td><td>Manufacturer</td><td>Carrier I</td><td>Distributor</td><td>Carrier II</td><td>Retailer</td><td>Carrier III</td><td>Customer</td></tr>
<tr><td colspan="5">Hierarchy / Partnership I</td><td colspan="2">Partnership II</td></tr>
<tr><td>Manufacturer</td><td rowspan="5">Hierarchy / Partnership I</td><td colspan="5" rowspan="5"></td><td colspan="2" rowspan="5">Seller</td></tr>
<tr><td>Carrier I</td></tr>
<tr><td>Distributor</td></tr>
<tr><td>Carrier II</td></tr>
<tr><td>Retailer</td></tr>
<tr><td>Carrier III</td><td rowspan="2">Partnership II</td><td colspan="5" rowspan="2">Buyer</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Customer</td></tr>
</table>

This structure makes a fundamental difference with regard to type II typological characters. We re-brand it with case evidence as presented below:

Table 8 Typological States Emerging from Case 2 and 3

Typological State	Feature	Case Evidence
Hierarchy-Hierarchy	Principle LM operator –customer	Tesco
Partnership-Hierarchy	(Principle LM operator + third-party provider) – customer	Dell
Hierarchy-Partnership	Principle LM operator – (third-party provider + customer)	Abby couriers, parcel motel

Partnership-Partnership	(Principle LM operator + third-party provider I) – (third-party provider II + customer)	Abby couriers, parcel motel

Table 9 Summary of Newly Proposed Typological Arrangement

Type	B2C distribution Procedural Step	Typological Character Relating to Network Node	Corresponding Typological State
Type I	Order Initiation	**Order placement point	**Existing stores
			**Customer location
	Order Fulfillment	Order fulfillment point	Existing store
			Distribution center
			Manufacturer
	Order Delivery	Order intermediary point	Distribution center
	Order Completion	Order Receipt Point	Customer location
			**Facilitator
			**Existing store
		**Inter-organisational Relationship Structure	**Principle B2C distribution operator –customer

			** (Principle B2C distribution operator + third-party provider) – customer
			**Principle B2C distribution operator – (third-party provider + customer)
			** (Principle B2C distribution operator + third-party provider I) – (third-party provider II + customer)

** starred elements are the ones that have been added to the original or somehow adjusted.

Understanding Food Safety Practices in Cross-border Supply Chain

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Abstract

This paper explores food safety issues and practices followed by food manufacturers, in an emerging country involved in a cross border supply chain, from supply network configuration perspective. Food safety is mainly associated with 'harm to health', however 'harm to emotion or beliefs' has recently emerged as an important food safety issue with horsemeat scandal. Ensuring food safety has emerged as one of the important industrial challenges, particularly when products are sourced from abroad. However, the understanding of practices adopted by developing countries in a rather complex global food supply chain is relatively vague. The study adopts framework of 'Six T's of Food Quality Management' and integrate it with 'the supply network configuration' approach to understand a set of practices promoting food safety in cross border supply chains. This integrated approach to food safety revealed new insights into how supply network configurations influence, enhance and promote operational food safety practices.

Keywords: Food supply chain, Indian food supply chain, Food safety

1 Introduction

Food safety concerns are receiving widespread attention due to the recent hi-profile food recalls (Bosona & Gebresenbet, 2013; Marucheck et al., 2011; Raspor 2008; Beulens, 2005; Grunert 2005). These incidents have resulted in hampering public confidence in the efficiency of food manufacturers and government in ensuring food safety (Gallop, 2008). Customer demand for year round availability of fresh and quality food has resulted in food supply chains being long, global and sometimes fragmented (Trienekens et al., 2012). In addition, recent safety hazards reiterate the fact that food safety is not a national concern but an international issue that needs immediate attention. As a result, food safety is emerging as an important industrial challenge (Unnevehr, 2000), particularly when the food is globally sourced (Marucheck et al., 2011). A list of recent hi-profile safety hazards and their impact is listed in Table 1.

Incident/ Product category/ References	Supply Chain Weak Link	Countries Involved	Impact
UK-Ireland Horsemeat scandal-2013/ Meat (Beef)/Verbeke, 2013	Food Labelling (Additive Ingredients Declaration)	13 European countries	“Immense cultural impact as horse meat was not usually consumed in Ireland. Muslims, Jews, Hindus were emotionally hurt and major retailers lost consumer's confidence. Sales of frozen hamburgers had fallen by 43% and frozen ready meals by 13% from levels before the scandal”. [Source: BBC]
German E-coli contamination of bean sprouts-2011/ Vegetables/(Karch et al., 2012	Farming (Contaminated seeds)	15 European countries, USA, Egypt(supplier)	“Estimated losses of $256 million” [Source: BBC]
Irish pork dioxin crisis-2008/ Meet (Pork)/ Casey et al., 2010	Farming (Contaminated Feed)	Ireland(supplier), UK, South Kora, Singapore, China, Japan	“Current estimated costs of the crisis stand at €100 million” [Source: Guardian]
Mad cow disease-2008/ Meat (Beef)/ Schlenker & Villas-Boas, 2009	Farming (Regulations - Inspection)	USA, Canada	“Company forced into bankrupcy($172 million) due to massive product recall and federal fines”. [Source: USDA]
Chineese milk scandal-2008/ Dairy / Pie at al., 2009	Processing (Adulteration)	USA, Denmark, Sweden, Japan, Taiwan, Hong Kong, Australia, Holland, Canada, Switzerland, China	“Company suffered $128 million losses leading to bankruptcy. EU announced a ban on imports of baby food containing Chinese milk” [Source: Guardian]
Salmonella outbreak in peanut butter-2007/ Dairy/ Maki, 2009	Infrastructure (Plant)	USA, Canada	“ConAgra spent around $78 million on the recalls. $55 million worth of lost sales. $15 to $20 million into renovating the responsible plan”. [Source: USDA]

Chinese petfood Chemical Contamination-2007/ Pet food/ Ingelfinger, 2008	Farming (Chemical Contamination)	USA, Canada, South Africa - China(Supplier)	“Around $42 million dollars to pay for the recall, excluding lost sales. $24-million settlement for pet-owners. $8 million paid out to affected consumers”. [Source: USDA]
Spinach E-coli outbreak-2006/ Vegetables/ Kotewicz et al., 2009	Farming (Water Contamination)	USA, Canada	“Estimated sales losses amounted to a staggering $350 million” [Source: NewYork Times]
Sudan I crisis in sause-2001/ Spices/ Umali-Deininger& Sur, 2007.	Processing (Adulteration)	UK, Europe, South Africa, India(supplier)	“Estimated worldwide damage of $198 million. Ban on export agencies in India”. [Source: Guardian]

Table 1: List of hi-profile food recalls and their impact

2 Literature review

2.1 Six T's of Food Quality Management

Traditionally, product safety has been viewed as a "technical problem" in areas like quality management and safety engineering. However, with increasing focus on operations research, operations management is being recognized as a means to manage safety. Roth (2008), through his insights from Chineese food recalls, categorized the practices that are critical to promotion of food safety and public health and introduced the "Six T's of supply chain quality management". Roths' (2008) "six T's" is reviewed to get a better understanding of how these "T's" promote food safety in global supply chains.

Traceability: Standard definition of traceability provided by International Organization for Standardization in 1994 explains traceability "as the ability to trace and follow a food, feed, food producing animal or ingredients, through all stages of production and distribution"(ISO standard 8402:1994). Since traceability involves historical study of certain activity or process in detail, traceability is also defined as "*the history of a product in terms of the direct properties of that product and/or properties that are associated with that product once these products have been subject to particular value-adding processes using associated production means and in associated environmental conditions"* (Regattieri et al., 2007). While traceability is a concept relevant to all product and supply network types, food safety is a principle factor that makes traceability a key instrument for mitigating product safety in food sector(Sarig, 2003) (Vorst, 2005).

Contemporary studies on food safety extend the concept of traceability to biotraceability (Ioana at al., 2013). An extension to traceability, biotraceability is defined as "the ability to identify the sources of microbial contamination in a food chain"(Smid et al., 2011). While traditional tracing process comprises of record maintenance and summarization of the same on a code or tag(Barker et al., 2009), biotracing is an emerging area that becomes an essential tool in assessment of microbiological hazards in food sector(Ioana et al., 2013). With most of the recent food scares involving detection of harmful microbiological contents, biotracing is an important aspect that should be present while designing traceability in food supply chains.

Transparency: Many researchers review transparency as a multi-faceted concept. A comprehensive understanding of transparency in supply chains is put forward by Hofstede(2003) and Deimel(2008); which states transparency as *". . .the extent to which all* *its stakeholders have a shared understanding of, and access to, the product-related information that they request, without loss, noise, delay and distortion".* In supply chains, scholars agree that information exchange, related to the origin and history of food products, is the fundamental factor enhancing visibility and thus transparency in the chain(Vorst, 2006). While the bare-minimum requirement for this information is its reliability, it should also be accurate, factual, relevant and available in required quantity (Hofstetde, 2003) which involves co-ordination of all the relevant actors in the network. When supply chain is defined as a "directed network of business processes", the factors realizing transparency of the network is dependent on these relationships (Beulens et al., 2005). Hence for exploring the concept of transparency in totality, a review of the supply network involved is essential.

Trust : Trust and commitment from all the actors in the chain is often referred to as an important factor in these relationships(Whipple & Frankel, 2008; Trauttman et al., 2009; Handfield & Betchel, 2002).While trust exists in various dimensions, Chowdary(2005) suggests that trust exists in agent-based and cognitive forms. Though the former is a result of behaviour and interaction frequency and latter with roots in "role-performance, cultural-ethnic similarity and professional credentials", both forms facilitated co-ordination, interaction and lower costs(Handfield & Betchel, 2002). While trust is an enabling factor of co-operation and co-ordination, Choi & Hong(2002) reviews that performance enabling mechanisms like joint agreements, vendor approval schemes or regular audits is a practical way in which focal firms maintain their supply base. Certifications and standards(both public and private) are said to enhance buyer-supplier relationships to promote total quality and safety(Raspor, 2008). In supply chain management where traceability and transparency are of critical importance, trust is of paramount importance(Roth et al., 2010) where each member has mutual confidence on other member's "capabilities and actions"(Johnston, 2004).

Training: With food supply chains tending to be long, global and highly interconnected (Trienekens et al., 2012. Marucheck et al., 2011), the importance of training is identified by many scholars (Fritz et al., 1989; Rangarajan et al., 2002). Roth et al.,(2011) explained that training including "technical assistance and transfer of best practices" is a critical necessity to harmonize "local norms" with "international expectations". Strategy and operations management literature explains the concept of training in the form of "learning-by-doing and "forgetting-by-not-doing"(Ardote, 1997) by establishing the risk of outsourcing. Standard training schemes abd behavioural training is found to be of utmost importance in food industry where most of the primary production processes are manual. Hygienic compliance training is identified as an important aspect of training in processing units (Carvalho, 2006; Egan et al., 2007). Though food safety training is identified as a means to assure public health, the effectiveness of these training schemes has been relatively unexplored(Roberts, 2008)

Time: Transit time is one of the critical parameters in food supply chain management affecting freshness and quality of the food products. Spoilage is high in case of frozen foods and longer transit times result in reduction of shelf life(Roth, 2011). Hence determining optimal lead time to prevent loss of production is emerging as an important industrial challenge, especially in global food supply chains(Lijima et al., 1996). In addition to transit time, Vorst(2005) proposes that traditional risk assessment in food supply chains should extend to evaluating the reaction time of the network to any disruptions. This leads to identification of critical points in the supply network and would reduce product recall time and volume if managed efficiently. Complex supply chains are prone to experience slowness in reporting disruptions, increasing operational risks(Roth, 2011).

Testability: In sectors like automobiles, electronics and aerospace, 100% product testing is a critical concept in product design (Peltzman, 1975; Haddadin et al., 2007; Kleyner & Sandborn, 2008). However, food product testing is impractical as foreign matter contaminations are not encountered as long as they do not alter the product characteristics (Roth et al., 2009). Historically, testing of food products is limited to varietal selection, validation of physical and visual characteristics, tolerance for foreign substance and compatibility of packaging materials(World Bank, 2007b). In fresh produce global trade, concerns around tolerance of pesticide residues, antimicrobial resistance, wax coatings, nanomaterials and genetically modified organisms are receiving increasing attention due to non-harmonization of these levels in each country(Domingo & Gine Bordonaba, 2011; Magnuson et al., 2011; Tait & Bruce, 2001). The important information on these residue levels(MRLs) can be found in the 1994 Agreements on the Application of Sanitary and Phytosanitary(SPS) Measures and Technical Barriers to Trade(TBT) of the WTO(Tran et al., 2013).

While MRL testing is mandatory for all the samples of produce according to the regulatory norms, end-product testing has been identified as an inefficient form of testing. Hence companies are rather focusing on prevention mechanisms like HACCP implementing in their production facilities to prevent contamination through external materials(Henson & Caswell, 1990).

2.2 Supply Network Configuration

In recent years, understanding the configuration of the supply network has evolved as a key element of managing the chain(Poirier & Bauer, 2001; Lamming et al., 2000, Srai & Gregory, 2008). Choi & Hong(2002) review supply network as an *"organization form in a larger context"* by extending the organizational design literature to capture the qualitative traits of supply networks in three dimensions – "formalization, centralization and complexity".

Integrating strategic management and operational management, a comprehensive supply network context is defined as "*that particular arrangement or permutation, of the supply network's key elements including, the "network structure" of the various operations within the supply network and their integrating mechanisms, the flow of materials and information between and within key "unit operations" the "role, inter-relationships, and governance" between key network partners, and the "value structure" of the product or service delivered"*(Srai & Gregory, 2008). Accordingly, the configuration mapping tools that provide a collective configuration of the supply network includes :

- Map capturing supply network structure
- Map capturing material and information flow between key processes
- Map depicting role of network actors and their relationships and governance
- Map explaining the value structure of the product/service

The structure of supply network is examined in three dimensions: horizontal structure, vertical structure and horizontal position of the focal company (Lambert et al, 1998) as shown in Figure 2.5. Complexity of the structure is termed as the "structural differentiation"(Daft, 1989). In simple terms vertical complexity refers to number of tiers in the network, horizontal complexity refers to number of suppliers in each tier and spatial complexity refers to the average time or distance between the participating firms(Choi & Hong, 2002).

Lamming et al(2000) identifies actors, resources and activities as the key elements of a network. The actors of the supply network are the critical firms that the focal company directly or indirectly interacts with. The flow of information and material is dependent on the key operational processes involved in the network.

Dynamics of the network are based on the inter-relationships between the network actors. In general, the actor that directly deals with consumer emerges as the network leader(Lambert et al., 1998). Governance is a necessity to ensure stability of buyer-supplier relationships(Benton & Maloni, 2005). In these relationships, governance comprises of "actions or mechanisms by which both parties behave, leading to fulfilment of joint objectives"(Liu et al., 2009). At product level, the value structure of the product or service includes the value adding activities of the firm. Some of the value propositions put forward by Srai & Gregory(2008) include product modularity(or shape), product differentiation, innovation, shelf life of the product and/or some key costs incurred by the structure.

3 Investigative framework

The existing literature identified the key food safety issues in global food supply chains and reviewed the importance of safety practices in ensuring food safety. However, extensive cross-country research in agri-food sector is minimal(Leat et al., 2009). Very little research is done on the operational safety practices in an emerging country which is a part of global food supply chains (World Bank, 2012). Moreover a key concerning fact is around the awareness of these practices among the manufacturers (Raspor, 2008). Literature review identifies that while there are ideal practices that promote safety, there is still uncertainty regarding the actual practices and their vulnerabilities especially in a developing country where the standards and infrastructure is not sometimes on par with international expectations. In addition, while much was discussed about the available practices, research on the kind of supply chain design strategies that foods manufactures adopt to imbibe safety into their chain is still very vague.

Supply chain perspective in food safety illustrates that safety issues can arise at any stage of the chain from farming through to distribution (Thirumalai & Sinha, 2011) and even at transfers during these stages or storage(Marucheck et al., 2011). Practices like traceability, transparency and trust, among others, depend significantly on the relationships between actors, co-ordination and maintenance of supply chain in totality. Hence in order to explore the safety practices in food supply chains, there is a need to review the supply chain configuration. A investigative framework is developed to explore food safety through supply chain configuration approach (Fig 1)

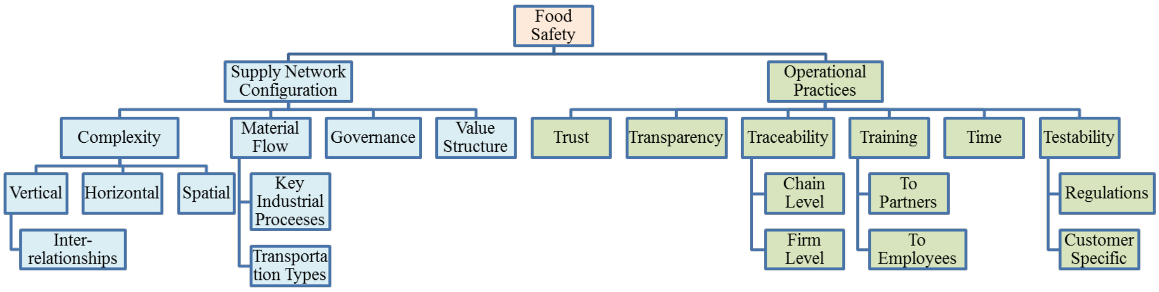

Figure 1: Investigative Framework

4 Approach

This research aims to understand how current food manufacturer ensures safety. Hence a case study approach was deemed fit. However, in order to maximize the ability to draw conclusions and external validity, multiple case study approach was recommended (Eisenhardt, 1989). To incorporate replication logic, this research employs multiple case study method to gather data. The study adopts the theory of "Six T's of Food Quality Management" and integrates it with supply network configuration approach to understand the comprehensive set of practices promoting food safety in cross border supply chains along with vulonerabilities. The research follows empirical approach, it was necessary to identify the inquiring factors, method for enquiry and sources of data. To facilitate structured data gathering, the investigative framework is developed, categorizing the key factors along with the set of factors influencing food safety is identified, as shown in Figure 1.

Selection of Countries, companies and product Categories: With the recent horse-meat scandal in UK, there is wide spread attention towards food safety practices of imported food. Hence the study of food safety practices in an emerging country that is serving the UK is of contemporary academic and industrial significance. With the food system in UK being one of the most sophisticated (Yakovlena et al., 2004), it was inferred that the practices enforced to attain the same amount of sophistication would be exemplary and the study of these practices would yield significant results.

A review of the importing countries and key issues in imported revealed that in developing countries, India accounts for 20% non-compliances[1]. Though India is a rapidly emerging country with agriculture as one of the key sectors for economic growth (Viswanadham,

[1] UK-FSA Sampling Report 2011, available at http://www.food.gov.uk/enforcement/monitoring/samplingresources/samplingandsurveillance/

2006), and in addition, extensive research on food safety in India is very scarce (Sihariya et al., 2013). This indicated that further research in focusing India is merited. The food supply chain activities are influenced by product characteristics (Ngam et al., 2008). Hence to limit the scope of the research, key product categories that India exports to UK are reviewed to find the category fit for the research. Among the value adding food exports from India to UK, Fresh Fruits and Marine products are of highest quantity. In addition, though there was evidence of collaborative initiatives in India to mitigate product safety, it has been lacking in horticultural sector (World Bank, 2007b). Though India is the 2nd largest producer of fresh fruits and 6th largest producer of fisheries, about 30% of the produce is lost due to contamination or inefficiencies of the cold chain (*Reardon & Minten, 2011).* Moreover, excessive usage of antibiotics has been a persistent issue in marine exports from India(World Bank, 2007b). With fresh fruits and fisheries being fresh products with less shelf life, food supply chains of these product categories are susceptible to higher degree of safety risk. Hence management of these chains is of significant importance (Unnverhr, 2000). For the above mentioned reasons, the scope of product categories is set to fresh fruits and marine products. To reduce extraneous variations, theoretical sampling method was employed. Companies that are known for key innovations in procurement and supply management were chosen to maximize the generalization of the results(Eisenhardt, 1989). Detailed selection criteria taken into account for selection of companies for case studies is as shown below

Category	**Selection Criteria/Company**	**Mahindra**	**Fishery Exporter**[2]	**Mahagrapes**	**Processed Food Exporter**[3]
Supply Chain Activity	Involved in cross border supply chain	√	√	√	√
	End-End chain activities control	√		√	√
	Processing/Pre-processing	√	√	√	√
	Intermediate Agents		√		
	Farming	√		√	√
Operational practices	Innovation in procurement strategies		√	√	√
	Innovation in supply chain practices	√		√	√
	Towards servitization in FSC	√			

Table 2: Company selection criteria

[2] Name is not disclosed to maintain anonymity as per company's request
[3] Name is not disclosed to maintain anonymity as per company's request

Data Sources: Data gathering was done through semi-structured interviews, documents and visual observations by visiting the companies in focus.An interview tool was designed to gain insights about company's back ground, supply chain activities and operational practices. In line with inductive learning(Michalski, 1983), the interview tool, without a fixed word structure, was developed to facilitate a two way informative discussion while making sure all the issues in the tool were discussed. Repeated visits (ranging from 2-3 days) were conducted to discuss additional criteria and ask the same question to different available informants in the company to be able to do data triangulation. Depending on the informant and the area of discussion, each interview lasted between 2– 4 hours in one sitting. Non-confidential documents like sample farm recommendation report, supplier performance ratings or vendor approval documents were requested from the firm, but put in closed confidence during the course of research. Where possible, a plant tour was requested from the participating company. This facilitated observation of practices like hygiene, sanitation in the firm. These observations helped in drawing conclusions about key behavioural practices followed in the company.

Data Analyses: Data Analysis was structured around key concepts derived from the literature – Supply network configuration and Six T's of quality management. Adopting Miles & Huberman's(1984) recommendations, initially a with-in case analysis was conducted to identify the different sets of operational practices. Later, a cross-case analysis was adopted to identify similar or differentiating patterns in the data acquired. While with-in case analysis identified the unique capabilities of the company's practices, cross case analysis brought about generalizations in the results. The key data was analysed and presented in the summary table (Table 3, 4, 5, 6, 7, 8).

	Practise	Mahagrapes	Mahindra Subhlabh Services Ltd	Fishery Exporter	Processed Food Exporter
Strategic Level (Supply Network Configuration)	Supply Network – Vertical Complexity	• Tier 1 Suppliers– Cooperative Societies, Logistics Firms, APEDA Certified Labs • Tier 2 Suppliers– Grape Growers • Tier 1 Customers – Importing Traders • Tier 2 Customers- Retailers	• Tier 1 Suppliers– Leased Pack Houses, Logistics Firms , APEDA Certified Labs, 3rd Party Agri services providers • Tier 2 Suppliers–Growers • Tier 1 Customers – Category Managers • Tier 2 Customers- Retailers	• Tier 1 Suppliers– Integrated processing plants, Logistics Firms, MPEDA Certified Labs • Tier 2 Suppliers–Local Markets • Tier 3 Suppliers – Hatchers • Tier 1 Customers –Traders, Re-processors, Distributors, Retailers • Tier 2 Customers- Retailers	• Tier 1 Suppliers – Integrated pre-processors, Farmers, Ingredient Suppliers, Govt. Labs • Tier 1 Customers – Intermediate processors, Retailers • Tier 2 Customers - Retailers
	Supply Network – Horizontal Complexity	• Tier 1 Suppliers- 16 Cooperative societies, 4 Logistics Firms, 6 APEDA Labs • Tier 2 Suppliers– 2700 Growers	• Tier 1 Suppliers- 17 leased pack houses, 2 APEDA Labs • Tier 2 Suppliers– 400 Growers	• Tier 1 Suppliers- 3 Integrated processing plants • Tier 2 Suppliers– 800 hatchers	• Tier 1 Suppliers – ~200 Approved Vendors, ~2500 Farmers • Tier 2 Suppliers - ~20 overseas retailers or processors
	Supply Network – Spatial Complexity	• Tier 1 to Tier 2: ~2 hrs • Tier 2 to Dispatch Port: ~5 hrs • Dispatch to Tier 1 Customers: ~1month •	• Tier 1 to Tier 2: ~2 hrs • Tier 2 to Dispatch Port: ~5 hrs • Dispatch to Tier 1 Customers: ~1month	• Tier 1 to Tier 2: ~4 hrs • Tier 2 to Dispatch Port: ~2 hrs • Dispatch to Tier 1 Customers: ~1month	• Tier 1 to Plant : 4-8 hrs • Plant – Dispatch Port: 6-8 hrs • Dispatch to Tier 1 customers: ~1 months

	Product Replenishment	Seasonal & Job Based	Seasonal & Job based	Job Based	Job Based
	Key Operational Processes	Harvesting, Grading, Packing, Pre-cooling, Cold storage, Export	Grading, Packing, Pre-cooling, Cold storage, Export Harvesting – 3rd party Service Providers	Pre-Processing(Cleaning, De-heading, Deveining, Skewing) Processing(Grading, Soaking, Glazing, Packing), Export	Grading, Processing, Packaging, Storage, Export
	Network Role/ Governance	Leader/Partner	Leader	Leader	Leader
	Network Relationships	Integrated	Integrated	Transactional	Integrated

Table 3: Within-case Summary – Supply network configuration analysis

	Six T	Mahagrapes	Mahindra Shubhlabh Services Ltd	Fishery exporter	Processing Food Exporter
Operational Level (Six T Framework for Quality Management)	Traceability	• 8 digit code(unique combination of farmer, co-operative society, location date of the processing • Bar Code technology	• Unique identification code(farm block and pack house). • Bar Code Technology	• Product code slip(based on product grade and type). • Julian Codes for the date of processing • Bar Code technology	• Unique traceability code based on batch number, lot number, date of processing • Farmer data base for origin of produce
	Transparency	• Mandatory registration of farmers in APEDA GrapeNet.	• Farm Recommendation Report(agro-chemical transactions with farmers) • Future plan to implement an ERP system • Mandatory registration of farmers in APEDA GrapeNet	• Mandatory maintenance of transaction documents(Sourcing team). • Integrated processing units registered under MPEDA(Export process control)	• Contract Farming • Farm Report(agro-chemical transactions with farmers) • Internal IT system for recording transactions • Mandatory maintenance of documents for 2 years
	Testability	• Residue sample testing(APEDA certified laboratories)	• Residue sample testing(APEDA certified laboratories) – Indian Regulations • Retailer sample testing(Overseas counterparts) – Imported Country Regulations	• Micro-bacterial and heavy metal testing(MPEDA certified laboratories) • Plants inspection by EIA - Health certificate and Q(quality) certificate	• Farm products: Mandatory pesticide analysis(NABL certified labs) - Once in every 15th -20th lot depending on product category • Packaging material: Migration certificate validity of food grade • In-house chemical testing laboratory • Plant certifications: IFS, BRC, HACCP, Kosher, FDA registration

	Training	• Employees - Need based training on International Practices(collaboration with universities in California). • Farmers - EUREPGAP and GLOBALGAP certified • Farmers - TESCO's Nature Choice Certification training	• Employees: Internal quarterly training programmes • Growers: Awareness training program(Visual Farm Recommendation Report) • Growers: GLOBALGAP certified • Pack houses: GLOBALGAP, BRC(4) and HACCP(2). •	Employees: Need based internal and/or external training schemes	• Employees: Food technology and quality training for qualified personnel(sponsored Harvard MBA programme) • Employees: Need based internal/external training programs to improve skill sets • Growers – Mandatory awareness training programs • Vendors – Quality awareness programs
	Trust	• Mutually beneficial co-operative society formation by farmers • Selection based on performance.	• Collaboration with farmers for a long term relationship(field staff) • Processing and distribution activities on behalf of farmers	• Purchase only from approved list of hatchers	• Long term relationships with farmers(contract farming) and vendors • Supplier base limited to approved vendors
	Time	• Tier 1 to Tier 2: ~2 hrs • Tier 2 to Dispatch Port: ~5 hrs • Dispatch to Tier 1 Customers: ~1month	• Tier 1 to Tier 2: ~2 hrs • Tier 2 to Dispatch Port: ~5 hrs • Dispatch to Tier 1 Customers: ~1month	• Tier 1 to Tier 2: ~4 hrs • Tier 2 to Dispatch Port: ~2 hrs • Dispatch to Tier 1 Customers: ~1month	• Tier 1 to Plant : 4-8 hrs • Plant – Dispatch Port: 6-8 hrs • Dispatch to Tier 1 customers: ~1 months

Table 4: Within-case Summary – Six T's of quality management analysis

	Mahagrapes	**Mahindra Shubhlabh Services Ltd**	**Fishery exporter**	**Processing Food Exporter**
Organization Structure	• Executive body members are elected expert farmers • Agricultural graduates - Technical managers	• CEO assisted by operational, quality and export managers are industrial eperts with ~10 yrs experience • Supported by regional quality field staff	• CEO assisted by general managers and business heads are industry experts with ~15 yrs experience • Product specific divisions	• CEO assisted by division heads and general managers(industry experts) • Separate division for quality and safety maintenance
Other Practices	• Production of bio-pesticides and bio-fungicides • Import of water purifying from Spain to reduce water contamination	• Visual recommendation report for increasing awareness • Mobile Safety Application real time data capture	• Use of Julian codes for improving traceability	• In-house water treatment plants • In-house hygienic storage areas for sensitive products • Allergen and ingredient management with limited access • CCTC camera monitoring for critical processes
Key Challenges	• Increasing pressure of retailers for certifications • Huge investment costs for sustaining infrastructure	• Lack of awareness of food safety among growers • Retailer specific residue levels(60 different residue levels) • Lack of availability of safe and effective chemicals permitted by international organization	• Shortage of power and cold chain • Shortage of skilled labour for processing processes	• Lack of awareness of food safety among framers • Increasing occurrence of plant infestants • Infrastructure inefficiencies in rural farmer base

Table 5: Within-case Summary – Other Practices

	Centralized	**Presence of middlemen**	**Competency based partners**	**Network Role /Governance**	**Direct interaction with retailers**	**Supply Network Weak-link**
Mahagrapes	Yes	No	No	Leader/Partner	No	Processing
Mahindra	Yes	No	Yes	Leader	Yes	Farming
Fishery Exporter	No	Yes	Yes	Leader	Yes	Processing
Processed Food Exporter	Yes	No	No	Leader	Yes	Farming

Table 6: Cross-case analyses of supply network configuration

	Traceability		**Transparency**		**Testability –** Residue sample		**Time**	**Training**		**Trust**	
	A1	**A2**	**B1**	**B2**	**C1**	**C2**	**D1**	**E1**	**E2**	**F1**	**F2**
Mahagrapes		Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Mahindra	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fishery Export Firm		Yes	Yes		Yes		No	No	Yes	No	No
Processed Food Exporter	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes

Table 7: Cross-case analyses – Summary of Six T's

A1	Chain Level Focus
A2	Firm Level Focus
B1	Physical documents
B2	Information sharing through technology
C1	Indian regulatory norms
C2	Retailer specific norms

D1	Focus to reduce transit time
E1	To partners
E2	To employees
F1	Focus on long term relationships
F2	Regular Audits/ Approval Schemes

Table 8: Legend for Six T's cross case analyse

4 Discussion

Supply Network Configuration – Structural Changes: The investigated companies are inclined towards an integrated chain which is centralized with the key responsibility lying in the hands of exporters. The exporting firm that deals with the retailers or overseas importers has emerged as the leader of the chain. Through this integrated chain, the companies have eliminated the presence of middlemen, which is a key characteristic of traditional Indian food supply chains. Lack of these middlemen also resulted in processors working closely with the framers facilitating knowledge transfer to the framers about the need and demand for food safety in developed markets. Such practices also lead to increase in the transparency of the chain with each actor being aware of all the other actors in the firm. For instance, Mahagrapes, MSSL and Processed Food Exporter have chosen to work directly with the farmers and employed field staff to monitor and guide them towards good agricultural practices. Through this, these companies are able to bring significant awareness among the framers and in addition, MSSL succeeded in increasing the farm yield by 15%.

All the key decisions including selection of vendors, logistics firms, safety system implemented or key performance benchmarks are controlled by the exporters. Another key trend observed was the selection of vendors or chain partners based on their core competencies. Companies have identified their core competency area and outsourced the operations that they don't expertise in to a third party firm which is an expert in that chain. This mechanism resulted in the best practices being followed in the chain. While MSSL has identified 3rd party service providers for harvesting the produce at the farm, Fishery Exporter and MSSL both leased the processing units from renowned plant owners in the area. With careful supervision of these operations, the companies have made sure that the shared objectives are met mutually. Moreover, Processed Food Exporter and MSSL has mechanisms like vendor approval schemes or performance analysis of vendors and farm recommendation report respectively to monitor their compliance and individual performances.

In addition, depending on the organization structure and the core competency of the chain, the weak-link in the chain differed. For instance, Mahagrapes, which is a farmer's society with expert farmers managing the chain activities, opined that processing is their key vulnerability while Mahindra and Processed Food Exporter who are experts in processing operations revealed that farm sector is their vulnerability. Thus by retrospection of their vulnerabilities from a network perspective, companies are strategically able to invest in mitigating these vulnerabilities.

Traditional Indian supply chain is characterized by the presence of local traders or wholesale distributers. However, for ensuring safety for exporting food products, a key practice observed was integrated supply chain by elimination of non-value adding intermediaries. Disappearance of middlemen resulted in increased transparency and traceability of the chain. Farmers are in direct contact with the processors under constant guidance and support which increased the awareness of safety and quality among the growers. Processors are now interacting directly with overseas retailers to learn specific requirements and consumer demands in the importing country. In addition, government, recognising the increasing demand for safety and public health, improved its regulatory norms, guiding agencies and participates in the chain by certifying laboratories for residue testing and approval schemes for processing plants.

Food safety practices: Companies are observed to have more inclination towards firm level traceability than chain level traceability. Among the data captured for traceability, chain level attributes like information about logistics partners or the product route was identified to be neglected in all the companies. Though records for critical transactions are maintained physically, information sharing through technology was observed only in MSSL and Processed Food Exporter. However, at firm level Processed Food Exporter made use of inventory management system to trace the products in their processing unit while MSSL has planned to implement ERP system to facilitate information sharing across the divisions in the company.

Though the Indian government has enforced GrapeNet as a means to improve transparency of transactions like pesticide usage and testing approvals, the lack of sufficient infrastructure in rural base has prevented in all the farmers taking advantage of this system. Hence it resulted in firms opting for their own transparency improving mechanisms like contract farming in the case of MSSL, Processed Food Exporters and co-operative society formation in Mahagrapes.

Due to national and international regulatory norms, exporters are emphasizing on sample testing for each batch of products. The exporters made use of APEDA, MPEDA or NABL certified laboratories for pesticide and residue analysis. In addition, exporters like MSSL, Fishery and Processed Food Exporters, realizing the risk of products being rejected if they failed to satisfy customer specific requirements for pesticide content, have started residue testing based on specific customer requirements to satisfy customer tolerances for critical parameters. It was observed that the focus was laid on reducing the transit time between tiers for fresh fruits. Since these products with shorter shelf life are highly perishable and sensitive to environment, Mahagrapes and Mahindra have set up processing units specifically to reduce the transit time and compensate for larger transit between exporting and importing nations.

All the companies visited have recognised the importance of training and knowledge transfer of good practices for increasing awareness of food safety. External and internal need based training schemes were embedded as a part of job responsibilities. In companies with centralized chains, chain level training is also observed to be in practice. For instance Mahagrapes, Mahindra and Processed Food Exporter have invested in training their framers and vendors accordingly to promote achievement of shared objectives across the chain. Fishery Food Exporter has contracts with regional labour unions to provide them with skilled and trained labour for processing operations.

Firms are engaging in developing long term relationships with their suppliers rather than limiting the interactions to just transactions. Mahagrapes, Mahindra and Processed Food Exporter informed that development of trust was identified as one of the key factors in sustaining these relationships. However, companies like MSSL and Processed Food Exporter are also conducting regular audits and inspections to assess the compliance of network actors. Another key observation made is the increasing focus on value adding activities in the chain. The companies recognizing consumer demand and perceptions for safety have indulged in activities that would improve the trust of their customers and add value to the product. For instance Mahagrapes, realizing consumer's inhibitions towards usage of agro-chemicals on the plants started manufacturing bio-pesticides and bio-fungicides under controlled environment. It also started importing water purifying reservoirs from Spain to avoid water contamination and reduce even the permitted chemical presence in their products. Processed Food Exporter has set up an in-house water purifying plant that supplies sterile water to the entire processing operations and also an in-house chemical testing laboratory to test the acid ratios of the products. In addition, in order to not hurt the cultural sentiments of consumers, Processed Food Exporter has started requesting non-GMO and HALAL declaration certificates from their suppliers apart from following the principles.

Through these collective activities, some of the firms are trying not only to improve consumer trust but also to improve the trustworthiness of the food sector in developing countries in general. The practices are summarized in Figure 2

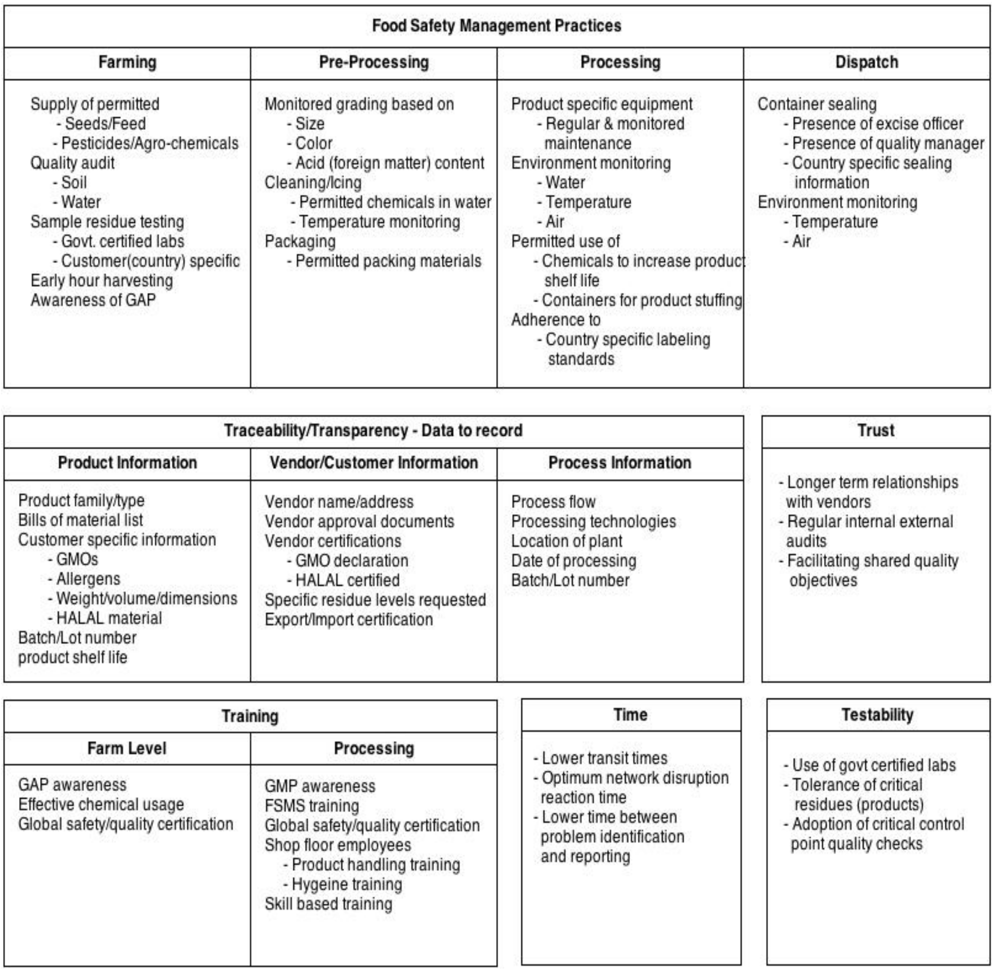

Figure 2: Summary of food safety operational practices

Key Vulnerabilities: After the operational practices in the industry were observed, a textual analysis against the best practices suggested by the literature resulted in identification of vulnerabilities in the practices followed. These vulnerabilities are summarized in Table 9

		Vulnerabilities	Ideal Practice
Traceability	Network Level	• GrapeNet – database of regulatory compliance data rather than data to trace • Lack of testing of capture data • Missing network level attributes - Logistics Partners - Product Route(with-in country) - Product Route(after port dispatch) - Characteristics of origin - Testing certificates/types	• Chain level dedicated system with open standards(Rigatteiri , 2007;Vorst, 2005) to facilitate testing of data • Key attributes(Rigatteiri , 2007) - Source of products & ingredients - Product characteristics - Consumer information - Product routing - Storage and movement systems • Enforcement of bio-traceability(Ioana et al., 2013;Smid et al., 2011)
	Process Level	Missing process level attributes - Manufacturing processes used - Detailed ingredients list(types/sources/testing)	
Transparency	Network Level	• Visibility of transactions limited to - Exporter - Importer • Information sharing system firm specific	• Maintaining information of(Gould, 2005) - Records of transactions - Goods/services - Multiple ports used • Access to all the actors (Deimel 2008;Hofstede 2003) • Information system for data sharing(Trienekens, 2012)
	Process Level		
Testability	Network Level	• Limited number of certified laboratories in the country (16-17) • Customer specific MRLs	• Standardization of testing requirements(Unnverhr, 2010) • Public-private partnerships to improve infrastructure facilities(Narrod, 2009)
	Process Level	Limited availability of • Permitted chemicals • Testing equipment	
Training	Network Level	• Increasing pressure of certifications from retailers • Shortage of skilled labour	• Mandatory Hygiene training along with GAPs(Seamon & Eves, 2006) • Behavioural training(Roberts et al., 2009). • HACCP standard adoption(Henson & Caswell, 1990)
	Process Level	HACCP limited to few processing units	
Time	Network Level	• Focus on transit time reduction only for perishable goods • Change of international regulations during transit of 1 month	Enforcements to reduce - Transit time - Reaction time - Time between problem identification and reporting (Roth, 2011)
	Process Level		
Trust	Network Level	Lack of direct consumer interaction	• Long term supplier relations(Cannon et al., 2010; Trauttman et al., 2009) • Performance enabling mechanisms(Choi & Hong, 2002) - Joint agreements - Vendor approval schemes - Specific standards • Measures to improve consumer trust(Grunert, 2005)
	Process Level	Burden of investments for customer specific trainings/certifications	

Table 9: Vulnerabilities in current food safety practices

5 Conclusion and further research

The study adopts the theory of "Six T's of Food Quality Management" and integrates it with supply network configuration approach to understand the comprehensive set of practices promoting food safety in cross border supply chains. Where before, six T's literature was found to promote food quality management, by extending the same with supply network configuration theory, this research provides a novel prototype approach to evaluate food safety practices management in global food supply chains by informing the set of best practices and vulnerabilities..

While the observations revealed the food safety practices followed in export food industry, it was also implied during the observations that the products not matching the international safety standards might enter the domestic supply chains. Due to institutional weaknesses, pesticide and residue testing requirements and lack of food safety, domestic food chains in India are inferred to have higher risk of contamination or adulteration. These processed food products that do not match the export trade quality entering the domestic chains might cause serious short, medium and long term effects to both public health and trustworthiness of the sector as well as hurt the sensitive emotions of consumers. The observations imply that the domestic food chains can also be made safer by adopting the practices followed in international trade market. Hence further industrial research about the food safety issues and suitability of these practices in domestic food supply chains might be of high merit.

The scope of the research was limited to fruits & vegetables and marine products. Since food supply chain activities are influenced by product characteristics, further research might be required in other food categories like meat products, dairy and poultry to generalize the results about the industry. The research was conducted in one developing country. To maximize the generalization of these results in other developing countries, further work would be involved to observe the same in other developing countries.

References

Argote, L. (2013). *Organizational learning: Creating, retaining and transferring knowledge*. Springer.

Asthana, S., Patkar, S., Natawidjaja, R., Widyastuti, C., Arya, S. S., & Shenoy, S. (2012) Small-scale farmers' decisions in globalised markets.

Athukorala, P. C., & Jayasuriya, S. (2003). Food safety issues, trade and WTO rules: a developing country perspective. *The World Economy*, *26*(9), 1395-1416.

Benton, W. C., & Maloni, M. (2005). The influence of power driven buyer/seller relationships on supply chain satisfaction. *Journal of Operations Management*,*23*(1), 1-22.

Beulens, A. J., Broens, D. F., Folstar, P., & Hofstede, G. J. (2005). Food safety and transparency in food chains and networks: Relationships and challenges. *Food Control*, *16*(6), 481-486.

Bhote K. (1987) Supply management: how to make U.S. suppliers competitive. *American Management Association*, 406-522.

Bosona, T., & Gebresenbet, G. (2013). Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food Control*.

Bremmers, H., Trienekens, J. H., van der Vorst, J. G., & Bloemhof, J. M. (2011). Systems for sustainability and transparency of food supply chains–Current status and challenges. *Advanced engineering informatics*, *25*(1), 65-76.

CAC (2003). Code of hygienic practice for fresh fruits and vegetables. In C. A. Commission (Ed.), *CAC/RCP 53–2003.*

Cannon, J. P., Doney, P. M., Mullen, M. R., & Petersen, K. J. (2010). Building long-term orientation in buyer–supplier relationships: The moderating role of culture. *Journal of Operations Management*, *28*(6), 506-521.

Carvalho, F. P. (2006). Agriculture, pesticides, food security and food safety.*environmental science & policy*, *9*(7), 685-692.

Casey, D. K., Lawless, J. S., & Wall, P. G. (2010). A tale of two crises: the Belgian and Irish dioxin contamination incidents. British Food Journal, 112(10), 1077-1091.

Choi, T. Y., & Hong, Y. (2002). Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler. *Journal of Operations Management*, *20*(5), 469-493.

Chowdhury, S. (2005). The role of affect-and cognition-based trust in complex knowledge sharing. *Journal of Managerial issues*, 310-326.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: more than a new name for logistics. *International Journal of Logistics Management, 8*(1), 1-14.

Daft, R. L. (2009). *Organization theory and design*. Cengage learning.

DEFRA. (2011). Agriculture in the United Kingdom. In F. a. R. A. Department for Environment (Ed.), (pp. 1-124). UK: Department for Environment, Food and Rural

Affairs.

Deimel, M., Frentrup, M., & Theuvsen, L. (2008). Transparency in food supply chains: empirical results from German pig and dairy production. *Journal on Chain and Network Science*, *8*(1), 21-32.

Egan, M. B., Raats, M. M., Grubb, S. M., Eves, A., Lumbers, M. L., Dean, M. S., & Adams, M. R. (2007). A review of food safety and food hygiene training studies in the commercial sector. *Food Control*, *18*(10), 1180-1190.

Engler, A., Henry, G., Iglesias, D., Alves, A. F., Gutierrez, G., Salay, E., ... & Jahn, G. (2007). Actor organization for QAS along agro supply chains: The case of mycotoxins reduction in Southern Cone grains. *Quality Management in Food Chains. Wageningen*, 475-488.

Frentrup, M., & Theuvsen, L. (2006). Transparency in supply chains: Is trust a limiting factor. *Trust and Risk in Business Networks, ILB-Press, Bonn*, 65-74.

Fritz, B. R., Cohen, N. L., & Evans, D. A. (1989). A food safety education program targeting food handlers in high risk settings. *Journal of Nutrition Education*, *21*(6), 284F-285F.

Gallup, A.M. (2008). The Gallup Poll Cumulative Index: Public Opinion, 1998-2007. *Rowman and Littlefield.*

Gawron, J. C., & Theuvsen, L. (2009). Certification schemes in the European agri-food sector: Overview and opportunities for Central and Eastern Europe.*Outlook on Agriculture*, *38*(1), 9-14.

Gawron, J. C., & Theuvsen, L. (2009). The international food standard: Bureaucratic burden or helpful management instrument in global markets? Empirical results from the German food industry. *Journal of International Food & Agribusiness Marketing*, *21*(4), 239-252.

Gottlieb, S. L., Newbern, E. C., Griffin, P. M., Graves, L. M., Hoekstra, R. M., Baker, N. L., ... & Sobel, J. (2006). Multistate outbreak of listeriosis linked to turkey deli meat and subsequent changes in US regulatory policy. Clinical infectious diseases, 42(1), 29-36.

Grunert, K. G. (2005). Food quality and safety: consumer perception and demand. *European Review of Agricultural Economics*, *32*(3), 369-391.

Haddadin, S., Albu-Schäffer, A., & Hirzinger, G. (2007, June). Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing. In *Robotics: Science and Systems*.

Handfield, R. B., & Bechtel, C. (2002). The role of trust and relationship structure in improving supply chain responsiveness. *Industrial Marketing Management*, *31*(4), 367-

382.

Haritz, M. (2009). Food safety, trust, and the European Union. In *A presentation at the Conference: Food Import Safety: Systems, Infrastructure, and Governance University of Wisconsin–Madison, Madison, WI*.

Henson, S., & Caswell, J. (1999). Food safety regulation: an overview of contemporary issues. *Food policy*, *24*(6), 589-603.

Henson, S., & Jaffee, S. (2008). Understanding developing country strategic responses to the enhancement of food safety standards. *The World Economy*,*31*(4), 548-568.

Henson, S., Saqib, M., & Rajasenan, D. (2005). *Impact of Sanitary Measures on Exports of Fishery Products from India: The Case of Kerala*. Rajiv Gandhi Institute for Contemporary Studies.

Hofstede, G. J. (2003). Transparency in netchains. *Information Technology for a better Agri-Food Sector, Environment and Rural Living. Debrecen University, Debrecen, Hungary*, 17-29.

Iijima, M., Komatsu, S., & Katoh, S. (1996). Hybrid just-in-time logistics systems and information networks for effective management in perishable food industries. *International journal of production economics*, *44*(1), 97-103.

Ingelfinger, J. R. (2008). Melamine and the global implications of food contamination. New England Journal of Medicine, 359(26), 2745-2748.

International Organization for Standardization (1994). ISO standard 8402:1994, http://www.iso.org.

Jensen, H. (2002). Optimal degrees of transparency in monetary policymaking.*The Scandinavian Journal of Economics*, *104*(3), 399-422.

Johnston, D. A., McCutcheon, D. M., Stuart, F. I., & Kerwood, H. (2004). Effects of supplier trust on performance of cooperative supplier relationships.*Journal of operations Management*, *22*(1), 23-38.

Karch, H., Denamur, E., Dobrindt, U., Finlay, B. B., Hengge, R., Johannes, L., ... & Vicente, M. (2012). The enemy within us: lessons from the 2011 European Escherichia coli O104: H4 outbreak. *EMBO Molecular Medicine*, *4*(9), 841-848.

Kirezieva, K., Jacxsens, L., Uyttendaele, M., Van Boekel, M. A., & Luning, P. A. (2013). Assessment of Food Safety Management Systems in the global fresh produce chain. *Food Research International*.

Kleyner, A., & Sandborn, P. (2008). Minimizing life cycle cost by managing product reliability via validation plan and warranty return cost. *International Journal of Production Economics*, *112*(2), 796-807.

Kondo, N. (2010). Automation on fruit and vegetable grading system and food traceability. *Trends in Food Science & Technology*, *21*(3), 145-152.

Kotewicz, M. L., Mammel, M. K., LeClerc, J. E., & Cebula, T. A. (2008). Optical mapping and 454 sequencing of Escherichia coli O157: H7 isolates linked to the US 2006 spinach-associated outbreak. Microbiology, 154(11), 3518-3528.

Kumar M. and Srai J. and Gregory M (2012), "Mapping of UK Food Supply Chains: Capturing Trends and Structural Changes", *XVI Annual International Conference of the Society of Operations, IIT Delhi, India*

Lambert, D. M., Cooper, M. C., & Pagh, J. D. (1998). Supply chain management: implementation issues and research opportunities. *International Journal of Logistics Management, The*, *9*(2), 1-20.

Lamming, R., Johnsen, T., Zheng, J., & Harland, C. (2000). An initial classification of supply networks. *International Journal of Operations & Production Management*, *20*(6), 675-691.

Lang, T., & Heasman, M. A. (Eds.). (2004). *Food wars: the global battle for mouths, minds and markets*. Earthscan.

Leat, P., & Revoredo-Giha, C. (2008). Building collaborative agri-food supply chains: The challenge of relationship development in the Scottish red meat chain. *British Food Journal*, *110*(4/5), 395-411.

Li, S., Visich, J. K., Khumawala, B. M., & Zhang, C. (2006). Radio frequency identification technology: applications, technical challenges and strategies. *Sensor Review*, *26*(3), 193-202.

Liker, J., & Wu, Y. C. (2006). Japanese automakers, US suppliers and supply chain superiority. *Supply chains and total product systems: a reader*, 177-96.

Littlefield, R. S. (2005). Jack in the Box: Lessons Learned by Accepting Responsibility. *LESSONS LEARNED ABOUT PROTECTING AMERICA'S FOOD SUPPLY*, 35.

Liu, Y., Luo, Y., & Liu, T. (2009). Governing buyer–supplier relationships through transactional and relational mechanisms: evidence from China. *Journal of Operations Management*, *27*(4), 294-309.

Loader, R., & Hobbs, J. E. (1999). Strategic responses to food safety legislation. *Food Policy*, *24*(6), 685-706.

Lu, H., Trienekens, J. H., Omta, S. O., & Feng, S. (2008). The value of 'guanxi' for small vegetable farmers in China. *British Food Journal*, *110*(4/5), 412-429.

Maki, D. G. (2009). Coming to grips with foodborne infection—peanut butter, peppers, and nationwide Salmonella outbreaks. New England Journal of Medicine, 360(10), 949-953.

Markman, G. D., Gianiodis, P. T., & Buchholtz, A. K. (2009). Factor-market rivalry. *Academy of Management Review*, *34*(3), 423-441.

Martinelli, K. A., & Briggs, W. (1999). Integrating public relations and legal responses during a crisis: The case of Odwalla, Inc. Public Relations Review, 24(4), 443-460.

Marucheck, A., Greis, N., Mena, C., & Cai, L. (2011). Product safety and security in the global supply chain: Issues, challenges and research opportunities. *Journal of Operations Management*, *29*(7), 707-720.

Massoud, M. A., Fayad, R., El-Fadel, M., & Kamleh, R. (2010). Drivers, barriers and incentives to implementing environmental management systems in the food industry: A case of Lebanon. *Journal of Cleaner Production*, *18*(3), 200-209.

McCullough, E. B., Pingali, P. L., Stamoulis, K. G., Haas, R., Canavari, M., Slee, B., ... & Anurugsa, B. (2010). Small farms and the transformation of food systems: an overview. *Looking east looking west: organic and quality food marketing in Asia and Europe*, 47-83.

Mohr, J., & Nevin, J. R. (1990). Communication strategies in marketing channels: a theoretical perspective. *The Journal of Marketing*, 36-51.

Negrini, R., Nicoloso, L., Crepaldi, P., Milanesi, E., Marino, R., Perini, D., ... & Ajmone Marsan, P. (2008). Traceability of four European protected geographic indication (PGI) beef products using single nucleotide polymorphisms (SNP) and Bayesian statistics. *Meat science*, *80*(4), 1212-1217.

Nicolau, A. I., Barker, G. C., Aprodu, I., & Wagner, M. (2013). Relating the biotracing concept to practices in food safety. *Food Control*, *29*(1), 221-225.

Pei, X., Tandon, A., Alldrick, A., Giorgi, L., Huang, W., & Yang, R. (2011). The China melamine milk scandal and its implications for food safety regulation. Food Policy, 36(3), 412-420.

Peltzman, S. (1975). The effects of automobile safety regulation. *The Journal of Political*

Economy, 677-725.

Poirier, C. C., & Bauer, M. J. (2000). *E-supply chain: using the internet to revolutionize your business: how market leaders focus their entire organization on driving value to customers*. Berrett-Koehler Store.

Rangarajan, A., Pritts, M. P., Reiners, S., & Pedersen, L. H. (2002). Focusing food safety training based on current grower practices and farm scale.*HortTechnology*, *12*(1), 126-131.

Raspor, P. (2008). Total food chain safety: how good practices can contribute?.*Trends in Food Science & Technology*, *19*(8), 405-412.

Reardon, T., & Minten, B. (2011). The quiet revolution in India's food supply chains. *New Delhi: International Food Policy Research Institute*.

Regattieri, A., Gamberi, M., & Manzini, R. (2007). Traceability of food products: General framework and experimental evidence. *Journal of food engineering*,*81*(2), 347-356.

Roberts, K. R., Barrett, B. B., Howells, A. D., Shanklin, C. W., Pilling, V. K., & Brannon, L. A. (2008). Food safety training and foodservice employees' knowledge and behavior.

Romano, P. (2003). Co-ordination and integration mechanisms to manage logistics processes across supply networks. *Journal of Purchasing and Supply Management*, *9*(3), 119-134.

Roth, A. V., Tsay, A. A., Pullman, M. E., & Gray, J. V. (2008). Unraveling the food supply chain: strategic insights from china and the 2007 recalls. *Journal of Supply Chain Management*, *44*(1), 22-39.

Schlenker, W., & Villas-Boas, S. B. (2009). Consumer and market responses to mad cow disease. American Journal of Agricultural Economics, 91(4), 1140-1152.

Seaman, P., & Eves, A. (2006). The management of food safety—the role of food hygiene training in the UK service sector. *International Journal of Hospitality Management*, *25*(2), 278-296.

Smid, J. H., Swart, A. N., Havelaar, A. H., & Pielaat, A. (2011). A practical framework for the construction of a biotracing model: Application to Salmonella in the pork slaughter chain. *Risk Analysis*, *31*(9), 1434-1450.

Smith, G. C., Tatum, J. D., Belk, K. E., Scanga, J. A., Grandin, T., & Sofos, J. N. (2005). Traceability from a US perspective. *Meat Science*, *71*(1), 174-193.

Soliman, F., Somaiah, K. P., Guptha, C. N., Harsha, N., Punith Maharshi, Y. R., Mangal, D., ... & Singh, K. (2013) Assessment of Implementation Success of Cloud Systems in

Innovative Supply Chain firms.

Sperber, W. H. (2009). Proposed World Organization for Food Protection. In *A presentation at the Conference: Food Import Safety: Systems, Infrastructure, and Governance University of Wisconsin–Madison, Madison, WI*.

Thakur, M., & Donnelly, K. A. M. (2010). Modeling traceability information in soybean value chains. *Journal of Food Engineering*, *99*(1), 98-105.

Thirumalai, S., & Sinha, K. K. (2011). Product recalls in the medical device industry: an empirical exploration of the sources and financial consequences. *Management Science*, *57*(2), 376-392.

Tran, N., Bailey, C., Wilson, N., & Phillips, M. (2013). Governance of Global Value Chains in Response to Food Safety and Certification Standards: The Case of Shrimp from Vietnam. *World Development*.

Trautmann, G., Turkulainen, V., Hartmann, E., & Bals, L. (2009). Integration in the global sourcing organization—an information processing perspective.*Journal of Supply Chain Management*, *45*(2), 57-74.

Trienekens, J. H., Wognum, P. M., Beulens, A. J., & van der Vorst, J. G. (2012). Transparency in complex dynamic food supply chains. *Advanced Engineering Informatics*, *26*(1), 55-65.

Tucker, J. B. (1999). Historical trends related to bioterrorism: An empirical analysis. Emerging infectious diseases, 5(4), 498

Umali-Deininger, D., & Sur, M. (2007). Food safety in a globalizing world: opportunities and challenges for India. Agricultural Economics, 37(s1), 135-147.

Unnevehr, L. J. (2000). Food safety issues and fresh food product exports from LDCs. *Agricultural Economics*, *23*(3), 231-240.

Van der Vorst, J. G. (2006). Product traceability in food-supply chains.*Accreditation and Quality Assurance: Journal for Quality, Comparability and Reliability in Chemical Measurement*, *11*(1), 33-37.

Van Wezemael, L., Verbeke, W., Kügler, J. O., de Barcellos, M. D., & Grunert, K. G. (2010). European consumers and beef safety: Perceptions, expectations and uncertainty reduction strategies. *Food Control*, *21*(6), 835-844.

Verbeke, W. (2013). Europe's horsemeat scandal is unfortunate, but it is not a full blown crisis. LSE EUROPP Blog.

Whipple, J. M., & Frankel, R. (2000). Strategic alliance success factors.*Journal of Supply Chain Management*, *36*(3), 21-28.

World Bank (2007b). India’s Emergent Horticultural Exports: Addressing Sanitary and Phyto-Sanitary Standards and Other Challenges. In *South Asia Sustainable Development,Development Department.*

Yakovleva, N., & Flynn, A. (2004). Innovation and sustainability in the food system: A case of chicken production and consumption in the UK. *Journal of Environmental Policy & Planning*, *6*(3-4), 227-250.

Zach, L., & Bier, V. (2009). Risk-based regulation for import safety. *Import Safety. Regulatory Governance in the Global Economy*, 151-70.

Frontiers of R&D Internationalisation Research in Recent Ten Years, A Systematic Review with Bibliographic Coupling Analysis

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Abstract:

This paper presented a systematic review of 621 literatures on R&D internationalisation from 2003 to 2012 in Web of Science. For every five years, the research frontiers on this topic are identified with the bibliographic coupling analysis. From 2003 to 2007, there are nine different frontiers while the hot research streams changed much from 2008 onwards. The summary and future research direction of the R&D internationalisation research have also been proposed based on the comparisons of the changes in frontiers.

Keywords: R&D internationalisation, R&D globalization, R&D network, global innovation network

1 Introduction

Prior to 1990s, the industrial research and development activities (R&D) were generally performed at the headquarters of the multinational (Niosi, 1999). However, the 1990s witnessed the fast growth of the internationalisation of R&D as a consequence of the implementation of global R&D strategies of the multinational corporations (MNC) (Yoichi, 1991). The global R&D strategy is both a challenge and an opportunity for many MNCs.

The growing trend of the global R&D activities in MNCs triggers the research on the internationalisation of R&D in management and international business areas. This topic had been well studied in recent decades, as many papers published to explore related issues. The increasing number of literature on the R&D internationalisation enables the bibliometric analysis for identifying the key research streams of this topic. The bibliometric analysis is usually used for capturing the big questions and identifying frontier topics from published literatures in a visualised and quantitative way (Culnan et al., 1990). This paper would present a systematic review on the internationalisation of industrial R&D using bibliometric methods.

In international business research, there are few papers that adopt the bibliometric method for systematic review on certain topic up to now. However, in other business and management fields, the bibliometric methods had been commonly used to identify the intellectual structure of the literature, such as the strategic management, innovation research, management information system and operations management (e.g. Ramos-Rodriguez & Ruız-Navarro, 2004; Culnan, 1986; Pilkington & Meredith, 2009).

The popularity of the bibliometric indicates it is a widely adaptive and valid method to be appropriately used for summarising and review of relevant literature on various topics in one discipline or across subjects (Tsai & Wu, 2010). The internationalisation of R&D in MNCs is a very distinctive research topic in international business, because R&D is a very unique functional and operational department in the MNCs. The internationalisation of R&D has many characteristics that could help to figure out this topic in the whole international business areas. Based on the large volumes of publications on the topic of internationalisation of R&D, it became necessary and useful to have a bibliometric analysis on the internationalisation of R&D. Therefore, the two objectives of this study are as follows:

(1) recognising the frontier research streams in R&D internationalisation areas in recent 10 years; and

(2) mapping the research gaps and future directions that are potential to become frontiers in the future in R&D internationalisation research.

This paper would briefly introduce the bibliometric methods first and then explain the detail of the implementation of the specific techniques, the bibliographic coupling methods including its data sources, procedures and related software used. Then, the results of the analysis would be reported in detail, linking the bibliometric patterns with the extant literature to find out the frontiers of the R&D internationalisation research. Finally, the summary of the findings would be highlighted to give suggestions for the future research directions of the R&D internationalisation.

2 Data and Methodology

2.1 Data Collection

As most previous works, the bibliographic data are collected from the ISI Web of Knowledge (WoK) (http://www.webofknowledge.com) that is usually regarded as the most important and common bibliographic database for citation analysis (Cobo et al., 2011). WoK contains all the journals that have been indexed in SCI and SSCI database, as well as all the citation information of the papers. Such comprehensive coverage of WoK implies the good quality of these journals. The bibliographic data are collected from the papers in ISI WoK with the following criteria: (1) title including internationali* R&D or internationali* innovat* (2) title including globali* "research and development" (3) title including "international R&D" or "international Research and Development" (4) title including "global R&D" or "global Research and Development" (5) title including globali* R&D or globali* innovat* (6) title including internationali* "research and development" (7) keywords including "R&D network" or "research and development network". This search includes a comprehensive set of literature on R&D internationalisation or globalisation and the R&D networks. In terms of the spelling difference, for instance, 'globalisation' and 'globalization', the search criteria were set with asterisk for. This symbol is attached to certain terms to address such spelling issue to get a broad dataset, covering most of the relevant literature. For example, the 'globali*' means any word that start with 'globali' should be matched in this search, however long the word is. Words such as globalised or globalization are all covered in the search, consequently.

The search with the above criteria was done on the June 20th, 2013. In total, 621 papers were found from WoK. The bibliometric analysis methods are implemented on these 621 papers with their 13350 references. The first paper explicitly on this topic (by the word 'explicitly', I mean the paper that matched the search criteria. Other papers might also discuss the R&D

internationalisation but did not labelled its title with internationalisation or globalisation or other related terms in the search criteria of R&D) was published in 1978. The paper within the criteria that get published each year is shown as follows. Notably, the number for 2013 ends on the date of the search, when it remains nearly another half year for 2013. There obviously is an increasing trend for the papers get published on this topic. Meanwhile, from the tendency line, the number of publications peaked at around 1999, when the internationalisation of R&D became more common in various industries. The other summit was in 2009. Such distribution of the number of papers published would be used as evidence for the time scaling.

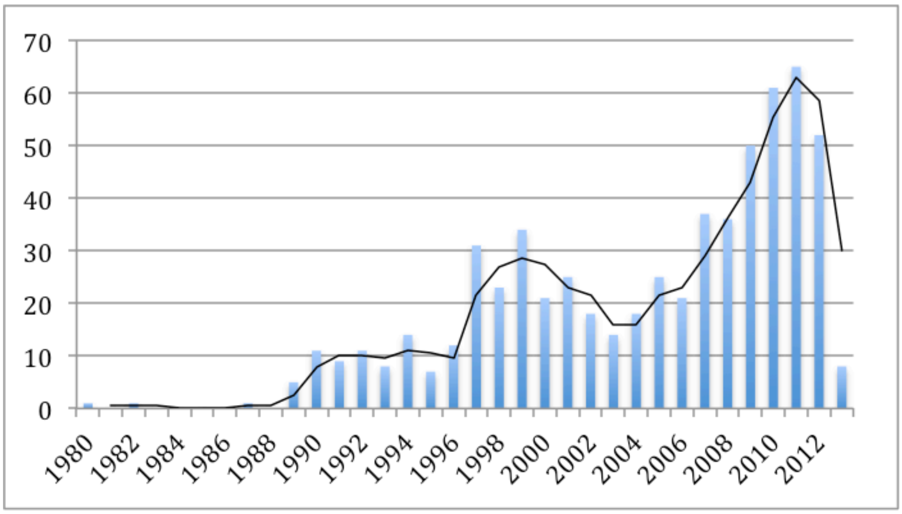

Figure 1 The number of relevant paper published yearly

2.2 Bibliographic Methodology

Bibliometric is a method associated the statistical analysis on counts and citing links between different articles in a body of literature (Culnan, 1986). A key assumption on bibliometric is that the references used in the articles provide information on the actual relationship between the article and other extant literature. Such analytic method is very common and well established to systematically review the literature on this research topic and map the structure of the discipline (Bensman, 2004).

The bibliometric methods have different variations in techniques. Different techniques are suitable for studies with different aims and objectives. The selection of these variations in techniques depends on the units of analysis, such as co-citation analysis for mapping the critical questions (Small, 1973), co-author for identifying knowledge exchange patterns (White & Griffith, 1981), bibliographic coupling for revealing the frontier research streams (White & McCain, 1998) and co-word analysis for understanding the development of the key concepts. In general, the bibliometric analysis could be used to review the literature from different perspectives in a quantitative way, based on the citation of papers or co-concurrency of words.

In order to map frontiers in R&D internationalisation research, this research would mainly based on the bibliographic coupling analysis, which is a common approach in the bibliometric methods to identify the research fronts (Persson, 1994). Many papers validated the effectiveness of the bibliographic coupling analysis to identify the patterns of frontier research streams in a domain of knowledge (e.g. Boyack & Klavans, 2010; Kessler, 1963).

The main advantage of bibliographic methods is to map a huge number of literatures in a scientific and quantified way whereas the drawbacks originate from the appropriate usage of reference (Bar-Ilan, 2008). Authors' referencing habit may depend not only on the intellectual relationship of papers, but also the accessibility of various articles and even the customs or mistakes of the authors.

Bibliographic coupling analysis is to identify the relationship between different papers according to their shared references. In other words, as Persson (1994) put, the bibliographic coupling method groups the cited papers based on the commonality in their reference lists, as the topics of two different papers may be quite related when two papers have similar references. The similar references are intellectual basis for the citing papers and with appropriate thresholds on the number and strength of the linkages between the coupled papers, bibliographic coupling is effective to identify the research frontiers (Glanzel & Czerwon, 1995 & 1996) by papers with high citations and large impacts on the scientific community. Compared with co-citation analysis, the advantage of bibliographic coupling is the ability to capture the early stages in defecting the research frontiers (Jarneving, 2007).

For this research, there are two purposes of the bibliographic coupling analysis, first to identify the hot research streams from the literature on the internationalisation of R&D in 2003 to 2007 and 2008 to 2012 respectively and, second, to identify possible evolutionary patterns during the changes of the hot topics in recent ten years.

The software used in this study for analysing the collected data for the analysis include both the specific software for bibliometric, such as the Science of Science (Sci2) Tool (Sci2 Team, 2009) and Citespace and the generic social network analysis software such as Pajek (Batagelj & Mrvar, 1998) and UCINET (Borgatti, Everett, & Freeman, 2002). These software had been widely used for bibliometric analysis in various disciplines (Cobo et al, 2011). The software usually shows a very good compatibility with the data derived from ISI WoK. Pajek and Ucinet are used to visualise all the analysis. The visualised methods only make the results more intuitive and the pattern of the mass literature clearer for the reader and researchers. Tables to summarise or presents the research findings would be preferred in order to have clear and scientific reports for the analysis.

This study follows a generic procedure for bibliometric analysis that includes the data extraction, defining of unit of analysis, selecting of measures, analysing and visualising (Börner, Chen, & Boyack, 2003). The data from WoK would first be extracted as a paper citation network, which includes various nodes to present an article and various edges that represent the citation relationship between the two papers. Thus, the matrix of bibliographic coupling is established and could be used for clustering the different research frontiers. In order to have a dynamic understanding of the evolving research agenda, the bibliographic coupling analysis would be conducted with different time scales. As this paper only traces the recent ten yeas, there would be two five-year periods for analysing. From 2003 to 2007, there were in total 124 papers. The number of papers doubled, reaching to 288, in the second period. For both periods, the bibliographic coupling analysis would be used for mapping the lasted hot questions. According to Glänzel & Czerwon (1996), a general criterion for selecting papers in effectively identifying the research frontiers is that the paper should have at least 10 links to other papers. Each link would connect two different papers into a path. Betweenness centrality is a common indicator for measuring the links in terms of both the weight of each link and the path to the papers (Chen, 2003). In these two periods, papers are chosen based on such criterion and cluster analysis would be used to identify the group of hot research frontiers that change with time. The bibliographic network is usually very complex with too many nodes and edges and general pruning methods, such as the minimum spanning tree pathfinder algorithm, would be used to decrease the dimensions and complexity of the network. The effectiveness of this algorithm has also been validated (Chen, 2003).

3 Results and Analysis

3.1 Hot Streams from 2003 to 2007

There are 128 papers from 2003 to 2007. The bibliographic citation identified 2958 papers, including these 128 papers and all their references without duplication. Six hundred and twenty links were found among the bibliographic coupled papers with the average weight of the link 2.0871. The key path identified from these 2958 papers is made of 88 nodes, as shown in Figure 3-1 below.

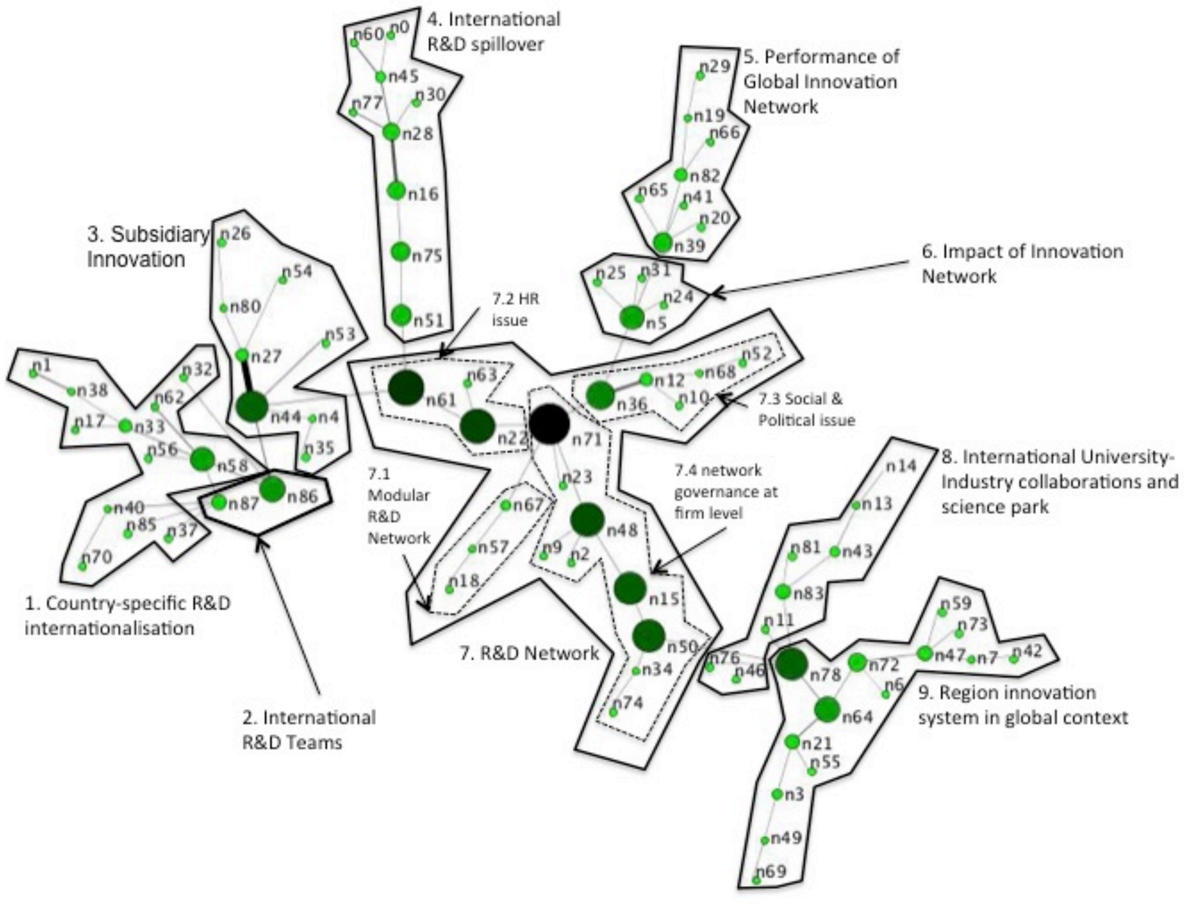

Figure 3-1 Clusters of the research frontiers: 2003 to 2007

In this graph, nine different research frontiers were identified. The first one was the country specific R&D internationalisation cases; several papers explored the R&D internationalisation activities of firms headquartered in different countries, such as China (Li & Yue, 2005) and Italy (Castellani & Zanfei, 2007). In particular, the prior activities are offshoring (Wu, 2007) and operation modes (Zhaohua & Jianhua, 2007) of subsidiaries. All these cases showed a clear picture that the industrial R&D activities is growing increasingly globalised and the frontier of research in this period is on the less developed countries. With large cases showing the globalisation of R&D, some researchers had a comprehensive review of these cases and highlighted the challenges and dilemmas in organising global R&D activities in general (von Zedtwitz, Gassmann, & Boutellier, 2004).

The second hot topic of R&D internationalisation research is about managing the international R&D teams in terms of the project management and coordination. Specifically, the contingent factors for successful multinational R&D project teams were research mandate and the market mandate of local R&D unit rather than cultural or geographic distance (Ambos & Schlegelmilch, 2004). The globalising R&D projects completed by international R&D teams is the main coordination mechanism for the international R&D management. Key factors for the successful coordination include standardisation of objectives, procedures and technology and good benchmarking system for evaluating the contributions of different participants (Mendez, 2003).

The third popular theme is on how to manage and promote the innovation of the subsidiaries. A special focus of this stream was on the Japanese MNCs' subsidiaries in the US (Iwata, Kurokawa, & Fujisue, 2006; Kurokawa, Iwata, & Roberts, 2007), and Chinese MNCs' (Nagasato & Tanabe, 2007). The knowledge-based view of firms is the mainstream to understand subsidiaries' innovation. The mechanism to promote innovation at subsidiaries consist of key elements that affected the knowledge flow to the subsidiaries, namely organisational structure of subsidiaries (Johnson & Medcof, 2007), the autonomy of subsidiary (Zhou, Fan, & Du, 2007) and its external linkages to local context (Helble & Chong, 2004). The knowledge flows would increase overall innovation performance of the subsidiaries, mediated by the accumulated knowledge of the subsidiaries (Kurokawa et al., 2007).

Another hot research is on the spillover effect of the international R&D FDI. The spillover effect was first explained by the cases of Taiwan's R&D FDI to mainland China (Chen, 2004), and Japan's FDI to Korea (Kwon, 2005). However, the latter case found insignificant spillover effects. A possible answer to this question may be the differentiation of the direct (e.g. knowledge, patent, etc) and indirect (e.g. intermediate goods) spillover, where the direct spillover effect was significant, as examined by Lee (2005). Further, the channels for the international R&D spillover, was identified, namely, the bilateral trade, FDI and information technology, especially the Internet (Zhu & Jeon, 2006, 2007).

The first four hot research themes are inner linked. They depicted the management of internationalisation of R&D at country, subsidiary and team level, together with the impact from the international R&D spillover. For the next three hot topics, they also consist under the theme of international R&D networks at the inter firm level, including the governance, influence and innovation performance of the network.

The fifth group of literature seeks to understand the effect of inter-firm innovation networks on the firm's innovativeness. A common finding is that firms should adopt different strategies when they are in distinctive positions, structures and relationships within the network in order to facilitate their innovation (Fang & Pigneur, 2007; Shen & Wang, 2006). This principle also applies to small and medium-sized companies to grow healthily in the global innovation network. It is notable that, absorptive capabilities were found as the key mediator to enhance the innovation performance of firms in the network of any positions, structures and relationships (Verburg, 2007).

The impact of the global R&D network had also been a research frontier in this period. The impact had been decomposed into three dimensions. Politically, the increasing global R&D

network calls for the new industry or innovation policy at both the regional and national level. Government should formulate new policy to facilitate the collaborative innovation between industry and the institutions (Audretsch, 2003). For the local community, the benefit of the R&D network is the spillover effect of the network, through the knowledge flow (Owen-Smith & Powell, 2004) whereas for the local firms, the global innovation networks provide opportunities to learn from and innovate. The innovation of the local firm should not be limited as the product or process innovation. Local firms may have to change their obsolete business models to survive or to integrate themselves into the network (Calia, Guerrini, & Mourac, 2007).

A large number of papers fall into the category of the governance of the international R&D network. To have an even brighter picture of these themes, sub categories are assigned to the subgroup of papers. The first hot topic within the R&D networks is the modular innovation network where MNCs and SMEs could collaborate closely as a platform with standardised modular (Dong, Zhang, & Sci Res, 2010; Qi, Wu, & Liu, 2007a; Qi, Wu, Wang, & Tang, 2007b; Wu, Qi, & Sheng, 2007). This dynamic platform includes two components: worldwide dynamic product networks and regional specialised innovation clusters. The modular platform enables the flexible strategy for firms to make use of global innovation resources quickly (Qi et al., 2007a). Some conditions, such as IT infrastructure are pre-required for such flexibility. The modular innovation network is a specific case for the governance of the network innovation network since the modularity or standardisation is only one of many possible means to manage the inter-firm R&D alliance.

A more generic approach for the management of the inter-firm R&D network constitutes three aspects. First of all, the governance of the inter-firm R&D network requires more complex human resource management, especially for knowledge mobility. Current mobility of researchers' is mainly due to the needs of specific projects and did not have long-term impact on the knowledge transfers among the R&D units (Criscuolo, 2005). Then, management of intra-firm R&D network dealt with the big problem to share knowledge to achieve common goals but remains the intellectual property of the core technology (Hagedoorn, Cloodt, & van Kranenburg, 2005). To win both sides, firms in the R&D alliance should not only have the governance mechanism and corresponding structure but also take the scope of the alliance into consideration (Oxley & Sampson, 2004). Managing the R&D network with governance and scope could effectively solve the dilemma (Hagedoorn et al., 2005; Oxley & Sampson, 2004). Several other key factors in the R&D alliance is the transaction cost and national culture, structural role and position of the firm in the alliance and the structural characteristics of the alliance (Chang, 2003; Riccaboni & Pammolli, 2003; Richards & Yang, 2007). At last, some political and social factors, such as technology policy, social capital and other social factors also have an impact on the R&D alliance, in terms of its productivity (Arranz & de Arroyabe, 2006) and structure (Arranz & de Arroyabe, 2007; Yu, 2007). This general approach depicts how to govern the R&D network at the team, alliance and industry level.

The last two categories are in relation to the regional issues of the internationalisation of R&D. The eighth hot topic includes the modes, process and performance of the international collaboration of the universities and the industries (Yu, 2006) with special focus to the function of the science park (Zhang & Chen, 2006; Zhang, Chen, & Yu, 2007). Such research broadens the scope the internationalising industrial R&D, since the R&D in the industries goes closer with the innovation in public sectors.

The last but not least popular research theme is about the regional innovation system in the globalising economic. The regional innovation system is more complicated than the international innovation network. The regional innovation system could nurture different industries to different extent, because of the varieties of the local knowledge base and institutional framework (Asheim & Coenen, 2006). In terms of these challenges to match both variable factors with the industry, effective approaches is to build up the regional innovation network for the core business or through the collaborative entrepreneurship (Asheim & Herstad, 2005; Matlay & Mitra, 2004; Pekkarinen & Harmaakorpi, 2006). Thus, from the government's perspectives, the policy should be tailored according to the industrial characteristics and the requirement of the regional innovation network in order to promote the innovativeness in the entire region (Tian & Zhang, 2007). However, with both the international network of firm's R&D alliance and regional innovation system, the technology transmitted even faster from the advanced countries to the developing ones. Some research examined the implications for the developing countries and found it depends on the nature of the technology and the policy of both the advanced countries to the developing ones (Archibugi & Pietrobelli, 2003).

3.2 Hot Streams from 2008 to 2012

There are 288 papers, from 2008 to 2012. The bibliographic citation identified 8852 papers, including these 288 papers and all their references without duplication. Nearly four thousand (3954) links were found among the bibliographic coupled papers with the average weight of the link 1.7851. The key path identified from these 8852 papers is made of 229 nodes, as shown in Figure 3-2 below.

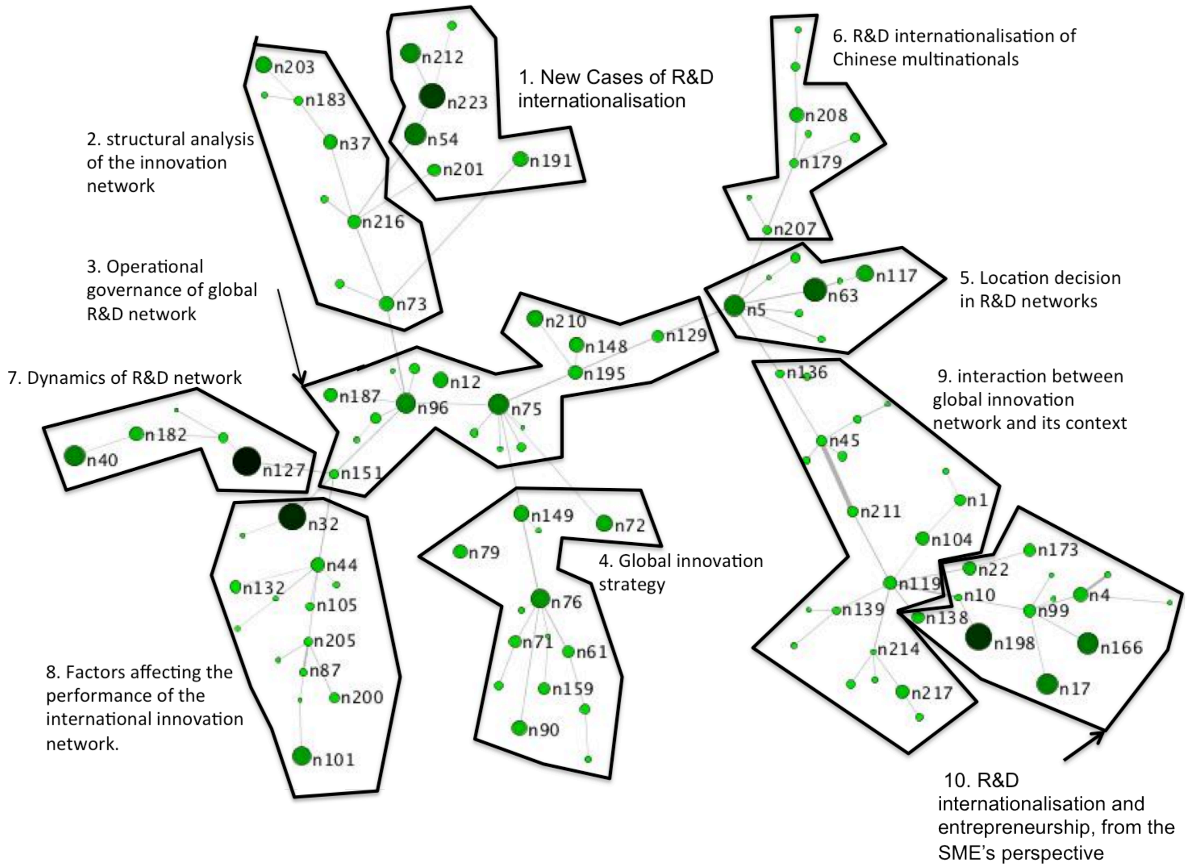

Figure 3-2 Clusters of the research frontiers: 2008 to 2012

The first hot stream is about further examinations of the R&D internationalisation. Several new cases had been developed to illustrate the characteristics of the R&D internationalisation in this period. National innovation networks were new forms in R&D network and had been studied with inter-industry network of Iran (Soofi & Ghazinoory, 2011) and Spain (Semitiel-Garcia & Noguera-Mendez, 2012) and one-industry network of Canada (Schiffauerova & Beaudry, 2012). It is interesting that without political intervention, the innovation diffusion and knowledge transfer with the national innovation network were insignificant, in particular for the inter-industry situations. Gatekeepers or hubs (Schiffauerova & Beaudry, 2012; Semitiel-Garcia & Noguera-Mendez, 2012) in such network could promote for innovation diffusion with the social or geographic proximity with limited effects. Thus, the local policy became a critical issue to support or even nurture a network. The government was identified as a new driver to establish knowledge networks (Choi, Park, & Lee, 2011), especially for emerging technology (van der Valk, Chappin, & Gijsbers, 2011).

The second frontier of the up-to-date research on R&D internationalisation was on the structural analysis of the innovation network from a holistic approach. Previously the structural analysis dealt with the best positions of the firms in the networks. During this period, the frontier's structural analysis was on the topologies (Salavisa, Sousa, & Fontes, 2012) and configurations (Corsaro, Ramos, Henneberg, & Naude, 2012) the innovation network. The informal and formal tiers could have been examined as key determinants (Salavisa et al., 2012) of the topological structure of the innovation network for accessing knowledge and complementary assets. The topological structure, or the configuration of the network could coexist in the same network (Corsaro et al., 2012). Thus, firms are able to make use of different configurations and the interaction between network configurations over their networks to create specific values. Further research (e.g. Riccaboni & Moliterni, 2009) suggested that the changeable and diverse configurations enabled firms to make use of the R&D network to manage the technological transitions in the dynamic context, with a stable and centralised structure. Meanwhile, in traditional structural analysis, the central nodes in the innovation network have been always the MNCs. Currently, the frontiers moved to the SME's which would lead and build up its flexible innovation network with different methods (Konsti-Laakso, Pihkala, & Kraus, 2012).

The third hot topic was on the governance of the global R&D network, but from a very tactic and operational perspective. Different industries were found to have different operations of their internationalising R&D alliances (Di Minin & Bianchi, 2011; Pavlinek, 2012; Shapira, Youtie, & Kay, 2011). The operations of the international innovation network seeks to find the market novelties and complementary competences (Freel & de Jong, 2009). Through the networking, firms could decrease the complexity of the innovation with multiple partners involved. While successful innovative collaboration with industrial partners requires similar operation modes (Berasategi, Arana, & Castellano, 2011) with different participants for sharing information and knowledge, the university and industry linkage in collaborations also have its operation modes (Wang, Liu, & Sun, 2010) as channels for knowledge and skills transfer. Those operative modes had been identified. The scope the R&D network had been again stressed (Lhuillery & Pfister, 2011). Besides networking by collaborations, the R&D outsourcing was found as the alternative mean (Martinez-Noya, Garcia-Canal, & Guillen, 2012) either to have cost advantages over innovation (outsourcing to the developing countries) or the strategic advantage to seek knowledge over innovation (outsourcing to the developed countries).

The fourth edge of research was related to the new strategies of the global innovation management. New situations in R&D internationalisation, such as the rise of the immediate outsourcing of R&D (Sener & Zhao, 2009), requested for new strategies in global innovation. At the firm level, the frontier focused no longer on the global innovation models of the established MNCs but changed gradually to the MNCs from the developing countries, in particular, China. MNCs in the emerging economies could should build up some basic innovation capability (Li & Kozhikode, 2009) and take advantage of the knowledge spillover from the R&D FDI to catch up. Meanwhile, MNCs headquartered in developing countries tended to prefer collaborating with local research institutes rather than firms during their R&D globalisation, especially in regions with heavy R&D FDI (Li, 2010). Further, a generic global management strategy was proposed as the R&D globalisation should interact with the local intellectual property protection (Li & Xie, 2011) in terms of the leaks of strategic knowledge. The open capital (Abouzeedan, Busler, & Hedner, 2009), a new term, was proposed to understand new tendency in the capitals for global innovation. At the national level, the previous research emphasised the large economies with regional innovation systems, whereas the recent research frontier is to understand the global innovation strategy for the small countries in their national innovation systems (Marcone, 2012; van Beers, Berghall, & Poot, 2008). For political implications, the government should formulate policy to support the transition of the innovation network to upgrade to the high-added value activities via the hubs in the network (Sener & Zhao, 2009).

Another hot research was in the stream of the location decision on the international R&D network. The determinations of the knowledge outsourcing is the lab's technological capability and ability to embed into the local environment (Song, Asakawa, & Chu, 2011). Meanwhile, the measure of innovation performance of international innovation was affected by the location factors (Bergek & Bruzelius, 2010). Thus, the location choice turns to be a very important reason, especially for outsourcing or offshoring to developing countries. Excellent locations shall have strong knowledge pools and knowledge exploitation system (Ambos & Ambos, 2009). On the other hand, firms could locate themselves properly in the international R&D network by analysing its intellectual properties, as the intellectual property served as the basis for coordination and defined the scope of different firms (Laperche, 2008).

The sixth hot research theme was on the R&D internationalisation of Chinese multinationals in terms of the driver, configuration of network, model and impact to China's development. Most Chinese MNCs with the global R&D strategy were driven by the technology and market scanning (Liu, Wang, & Zheng, 2010). They usually adopt a centralised configuration model with some variaties (Liu et al., 2010), where the headquarter's R&D department contributed nearly all to the innovation of the company. Their path of R&D internationalisation, unlike the MNCs from developed countries, followed a learning process with exploration, fusion and exploitation (Di Minin, Zhang, & Gammeltoft, 2012).

Seventh, another popular theme was on the dynamic of the global R&D network. The analysis of the R&D network over time confirmed the increasing collaborations in R&D activities worldwide (Bojanowski, Corten, & Westbrock, 2012). Both the structure of the network and the number of innovators in the network influences the dynamics and spillover of the network (Bojanowski et al., 2012). The R&D network had its own cyclic closure and preference attachment effect during its dynamics (Hanaki, Nakajima, & Ogura, 2010). A key problem lied in the dynamics of R&D network is the talent cultivations (Li, Wu, & Gao, 2009), as R&D is knowledge intensive activities and requires advanced talents.

The next hot stream is about identifying the factors affecting the performance of the international innovation network. This includes the firms openness (Enkel, 2010) and positional advantages, cultural issues in knowledge management (Li, Eden, Hitt, & Ireland, 2012), the strength of R&D network tiers (Bertrand-Cloodt, Hagedoorn, & Van Kranenburg, 2011), the dynamics (Gardet & Mothe, 2011) and modes (Gardet & Fraiha, 2012) of coordination within the network. Further, the relationship between the R&D internationalisation and the innovation performance have been re-examined. Specifically, the internationalisation had mutual relationships with the technological innovation (Filipescu, Rialp, & Rialp, 2009) and service innovation (Rodriguez & Nieto, 2010) and was endogenously related to the knowledge creation by global R&D leaders (Filipescu et al., 2009). The relationship between the indigenous innovation of China and globalisation had also been established.

Ninth, the interaction between global innovation network and its context had been explored as a new frontier. The growing institutional forces worldwide calls for the sustainability of industry and business, drives the innovation network taking the environment-friendly into consideration in their innovation (Cainelli, Mazzanti, & Montresor, 2012) and corresponding policy to promote such eco-innovations should benefit the competitiveness of firms with the assistance of NGOs (Kemp, Soete, & Weehuizen, 2012). The internationalisation of R&D firms in the global innovation network had an impact over the local development and innovativeness (Sedita, Belussi, & Fiscato, 2011). As thus, national policy should support such activities and build up the national innovation capability accordingly (Huang, Shih, & Wu, 2010). The key element for policy-making is the firms' positions in the global innovation network and partnerships and channels for innovation diffusion.

The last hot topic is on the R&D internationalisation and entrepreneurship, from the SME's perspective. The entrepreneurship is highly correlated with the R&D internationalisation (Filatotchev & Piesse, 2009; Yu & Si, 2012). In return, globalisation of innovation is also closed related to the entrepreneurial talents that set up the international SMEs by various means, such as new ventures (O'Cass & Weerawardena, 2009; Wuebker, Acs, & Florida, 2010). The SMEs with the entrepreneurial talents could tap the social knowledge, a moderator to enhance the SEM's innovation performance, into the innovation network (Zahra, Ucbasaran, & Newey, 2009). For SMEs, the serial innovation could enable them to benefit most from the internationalisation and industrial clusters (Libaers & Meyer, 2011). The two typical innovation orientation had resulted in different the internationalisation path, either the gradual process or the rapid transition one (Melia, Perez, & Dobon, 2010).

4 Conclusion

The intellectual structures of the research frontiers in R&D internationalisation had been mapped with standardised bibliographic coupling analysis. The evolving of the research frontiers in the R&D internationalisation in recent ten years had been clearly illustrated and systematically examined. Comparing these two structures, some remarkable conclusions are as follows.

Researchers are seeking for new cases of R&D internationalisation. From 2003 to 2007, the cases of R&D internationalisation were mainly about the R&D internationalisation of MNCs in specific industries in certain nations while for the recent 5 years, the cases were however on the multiple industry cases or policy driven internationalisation of R&D, while the focus of such research moved to the MNCs from developing country such as China.

New types of R&D practice in new cases of R&D internationalisation called for new management techniques. Thus, the management of R&D network was also an ongoing topics in this area to deal with different new management issues. The governance model of global innovation network was the main topic from 2003 to 2007, including the standardised model of governance with modular network, the knowledge sharing and intellectual property protection and contextual factors influencing governance. This topic expanded into three different streams five years later. The first stream is the structural analysis of, from a holistic approach, the R&D network including the typology, roles of each node and their interactions. Then, at the operational level, firms's operation modes, scopes and options (such as sourcing) of the network has also been examined. The last stream is from the strategic angle, where the global R&D strategy for configuring the global network of innovation has been well developed.

The research on regional innovation system (RIS) and internationalising R&D was in the frontier in this topic from 2003 to 2007. This topic was actually discussing the relationship between the R&D internationalisation (its spillover in particular) and its consequence to the local environment especially the local innovation system. Later researchers tried to further the study by exploring the interactions between the RIS and the global innovation network, which may include the mutual spillover effect and integrate these two systems for effective innovation. The policy implications for local government has often been highlighted.

Besides all these long last hot topics, some hot topics however cooled down from one period to another. Managing R&D teams in international context was very hot from 2003 to 2007, as the human resource lies in the heart of the R&D activities. The mechanism for cooperation worldwide required the standardisation of different objectives and procedures for the projects. This rule is widely accepted and made it few rooms for future exploration.

Meanwhile, the collaboration of the university and industry was very hot around 2003. Universities played a very important role in collaborations with firms to deliver new scientific and technological breakthrough. The global university and its graduates are very attractive pools for the R&D department in industry. New modes were found for firms to collaborate with the universities worldwide. Due to the slow progress in such collaboration, the research at the university and industry links also faded.

The social and political impact of the global innovation network, especially with the positive influence on international trade and economic growth had also been cooled down, as some remarkable conclusions were identified. Similarly, spillover of international R&D was clearly identified and examined in the first period and was no longer hot recently.

There are also some new hot topics emerging in the research within recent five years. As the R&D network developed for a long time, it became possible to study the dynamics of the inter-form R&D network over time. Those researches tried to understand the structural dynamics of the network, in order to identify the suitable governance mechanism and effective network configuration for better innovation performance. Further, as the innovation became more global and open, the internationalisation of R&D promoted the entrepreneurship worldwide, which also became a new frontier.

Such development of the research frontiers over the recent ten years showed that the core topics in the R&D internationalisation is always the management and performance of the R&D network and the new cases for internationalisation of R&D. Such management became more specific and diverse in terms of the complexity of the global R&D management. While the changeable frontiers are research on understanding or managing the internationalising R&D from other academic disciplines, such as HR, international trade, etc. Such new perspectives on the R&D globalisation would be hot for a while. However, when back to its nature, new perspetives on this topic often provided evidence to support or understand the management of R&D networks from other angles. Thus, such new understanding had been integrated into the mainstream of the R&D internationalisation research and no longer kept hot.

Some other remarkable trends are as follows. The focus of the R&D internationalisation moved from developed countries to emerging economies and from the MNCs to SMEs. The governance of the network upgraded from an operational perspective to a strategic view. Dynamics of the R&D networks would be likely to revisit. The internationalisation of R&D and its impact over the regions has integrated with regional studies, policy science and the economics.

Meanwhile, the development of R&D internationalisation for the a long period offered other opportunities for research. Based on all of the tendency above, some new research directions would be as follows. First, up to now, the most research in latest ten years focused on the inter-firm R&D network within ten years. The intra-firm network of R&D department within one firm had not been carefully examined in terms of the working mechanism within the firm and collaboration approach with other firms. For the multinationals, they have to take the advantages of all their R&D units worldwide to tap and leverage the global R&D resources. Thus, it is necessary to understand how the intra-firm network works in order to help firms have better innovation performance and have better link with the global market.

Secondly, for the management of the intra-firm network, the current research mainly focused on the network structure, dynamics and configurations. These studies analyzed the external characteristics of the networks. Firms integrate their R&D units into the network. The R&D units in such a network are managed by R&D department. The R&D network was implicitly influenced by their headquarters' characteristics in R&D management. Thus, it is reasonable to have further investigation on the interaction of R&D management and the R&D network governance. Meanwhile, the mechanism of how a firm could establish its R&D network, both at the inter-firm and intra-firm level have not been systematically answered. For this question, a possible approach is to understand such mechanism with all the factors that affect the performance of the R&D network. Identifying these factors was a research frontier from 2008 to 2012.

Last but not least, the various cases for internationalisation of R&D in different industries and countries may be integrated to a holistic or comparative view on the R&D internationalisation. Such integration would reveal whether there exist general approach for the R&D internationalisation, or whether the R&D internationalisation follows a contingent manner that varies across nations and industrial sectors. The holistic or comparative view of the R&D globalisation would help firms to understand the millstones in the process of R&D globalisation. Integrative models of the R&D internationalisation theory would make contributions to the international business theory and/or the innovation theory, as the fragmented research in these areas have been systematised.

To conclude, this paper found out the research frontiers in the R&D internationalisation literature in recent ten years. By comparison of the two periods, some remarkable characteristics of the R&D internationalisation research had been summarised, together with the future research directions. However, this research also has its own limitations. The clustering should have further consolidation with factor analysis to improve the accuracy. To have a comprehensive understanding on the intellectual structural of the this research topic, the cocitation analysis should be adapted, as it is complementary to bibliographic analysis to identify the big questions and make result more robust.

Reference

Abouzeedan, A., Busler, M., & Hedner, T. 2009. Managing Innovation in a Globalised Economy: Defining the Open Capital. In A. Ahmed (Ed.), *Impact of the Global Financial Crisis on the Environment, Energy and Sustainable Development*: 287-294. Brighton: World Assoc Sustainable Development-Wasd, Spru-Science & Technol Policy Res.

Ambos, B., & Ambos, T. C. 2009. Location choice, management and performance of international R&D investments in peripheral economies. *International Journal of Technology Management*, 48(1): 24-41.

Ambos, B., & Schlegelmilch, B. B. 2004. The use of international R&D teams: an empirical investigation of selected contingency factors. *Journal of World Business*, 39(1): 37-48.

Archibugi, D., & Pietrobelli, C. 2003. The globalisation of technology and its implications for developing countries - Windows of opportunity or further burden? *Technological Forecasting and Social Change*, 70(9): 861-883.

Arranz, N., & de Arroyabe, J. C. F. 2006. Joint R&D projects: Experiences in the context of European technology policy. *Technological Forecasting and Social Change*, 73(7): 860-885.

Arranz, N., & de Arroyabe, J. C. F. 2007. Administrative and Social Factors in the Governance Structure of European R&D Networks. In G. Cliquet, G. Hendrikse, M. Tuunanen, & J. Windsperger (Eds.), *Economics and Management of Networks: Franchising, Strategic Alliances, and Cooperatives*: 293-311. New York: Springer.

Asheim, B. T., & Coenen, L. 2006. *The role of regional innovation systems in a globalising economy Comparing knowledge bases and institutional frameworks of Nordic clusters*. London: Routledge.

Asheim, B. T., & Herstad, S. J. 2005. Regional Innovation Systems, Varieties of Capitalism And Non-Local Relations: Challenges From The Globalising Economy. In R. A. Boschma, & R. C. Kloosterman (Eds.), *Learning from Clusters: A Critical Assessment from an Economic-Geographical Perspective*, Vol. 80: 169-201. Dordrecht: Springer.

Audretsch, D. B. 2003. *Entrepreneurship, innovation and globalization: Does Singapore need a new policy approach?* Cheltenham: Edward Elgar Publishing Ltd.

Bar-Ilan Judit, 2008. Informetrics at the beginning of the 21st century- A review, Journal of Informetrics 2, 1–52.

Batagelj & Mrvar, 1998, Batagelj,V., & Mrvar,A. (1998). Pajek-Program for large network analysis. *Connections*, 21(2), 47–57.

Bensman, S.J., (2004). Pearson's R and author co-citation analysis: a commentary on the controversy. *Journal of the American Society for Information Science and Technology,* 55(10), 935-936.

Berasategi, L., Arana, J., & Castellano, E. 2011. A comprehensive framework for collaborative networked innovation. *Production Planning & Control*, 22(5-6): 581-593.

Bergek, A., & Bruzelius, M. 2010. Are patents with multiple inventors from different countries a good indicator of international R&D collaboration? The case of ABB. *Research Policy*, 39(10): 1321-1334.

Bertrand-Cloodt, D., Hagedoorn, J., & Van Kranenburg, H. 2011. The strength of R&D network ties in high-tech sectors - a multi-dimensional analysis of the effects of tie strength on innovation performance. *Technology Analysis & Strategic Management*, 23(10): 1015-1030.

Bojanowski, M., Corten, R., & Westbrock, B. 2012. The structure and dynamics of the global network of inter-firm R&D partnerships 1989-2002. *Journal of Technology Transfer*, 37(6): 967-987.
Börner, K., Chen, C., & Boyack, K. (2003). Visualizing knowledge domains. *Annual Review of Information Science and Technology*, 37, 179–255.
Borgatti, S.P., Everett, M.G.,&Freeman, L.C. (2002). *Ucinet 6 for Windows: Software for social network analysis, analytic technologies*, Harvard, MA.
Boyack, K. W., & Klavans, R. 2010. Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately? *Journal of the American Society for Information Science and Technology*, 61(12), 2389-2404.
Cainelli, G., Mazzanti, M., & Montresor, S. 2012. Environmental Innovations, Local Networks and Internationalization. *Industry and Innovation*, 19(8): 697-734.
Calia, R. C., Guerrini, F. M., & Mourac, G. L. 2007. Innovation networks: From technological development to business model reconfiguration. *Technovation*, 27(8): 426-432.
Castellani, D., & Zanfei, A. 2007. Internationalisation, innovation and productivity: How do firms differ in Italy? *World Economy*, 30(1): 156-176.
Chang, Y. C. 2003. Benefits of co-operation on innovative performance: evidence from integrated circuits and biotechnology firms in the UK and Taiwan. *R & D Management*, 33(4): 425-437.
Chen, C. (2003). *Mapping scientic frontiers, the quest for knowledge visualization*. London: Springer-Verlag
Chen, S. H. 2004. Taiwanese IT firms' offshore R&D in China and the connection with the global innovation network. *Research Policy*, 33(2): 337-349.
Choi, H., Park, S., & Lee, J. D. 2011. Government-driven knowledge networks as precursors to emerging sectors: a case of the hydrogen energy sector in Korea. *Industrial and Corporate Change*, 20(3): 751-787.
Cobo M.J., López-Herrera A.G., Herrera-Viedma E. and Herrera F, 2011. Science Mapping Software Tools: Review, Analysis, and Cooperative Study Among Tools, *Journal of The American Society for Information Science and Technology*, 62(7):1382-1402.
Corsaro, D., Ramos, C., Henneberg, S. C., & Naude, P. 2012. The impact of network configurations on value constellations in business markets - The case of an innovation network. *Industrial Marketing Management*, 41(1): 54-67.
Criscuolo, P. 2005. On the road again: Researcher mobility inside the R&D network. *Research Policy*, 34(9): 1350-1365.
Culnan MJ, (1986) The Intellectual Development of Management Information Systems, 1972-1982: A Co-Citation Analysis, *Management Science*, 32,(2), 156-172.
Culnan MJ, O'Reilly CA, Chatman JA., (1990). Intellectual structure of research in organizational behaviour, 1972–1984: a co-citation analysis. *Journal of the American Society for Information Science* 41:453-458.
Di Minin, A., & Bianchi, M. 2011. Safe nests in global nets: Internationalization and appropriability of R&D in wireless telecom. *Journal of International Business Studies*, 42(7): 910-934.
Di Minin, A., Zhang, J. Y., & Gammeltoft, P. 2012. Chinese foreign direct investment in R&D in Europe: A new model of R&D internationalization? *European Management Journal*, 30(3): 189-203.
Dong, J. W., Zhang, T., & Sci Res, P. 2010. *Modular Innovation Network: A Review about Management Strategies*. Irvin: Sci Res Publ, Inc-Srp.

Enkel, E. 2010. Attributes required for profiting from open innovation in networks. *International Journal of Technology Management*, 52(3-4): 344-371.
Fang, G., & Pigneur, Y. 2007. *The integrative model of international innovation network and performance*. Cambridge: Univ Cambridge, Inst Manufacturing.
Filatotchev, I., & Piesse, J. 2009. R&D, internationalization and growth of newly listed firms: European evidence. *Journal of International Business Studies*, 40(8): 1260-1276.
Filipescu, D. A., Rialp, A., & Rialp, J. 2009. Internationalisation and Technological Innovation: Empirical Evidence on Their Mutual Relationship. In R. R. Sinkovics, & P. N. Ghauri (Eds.), *New Challenges to International Marketing*, Vol. 20: 125-154. Stamford: Jai Press Inc.
Freel, M., & de Jong, J. P. J. 2009. Market novelty, competence-seeking and innovation networking. *Technovation*, 29(12): 873-884.
Gardet, E., & Fraiha, S. 2012. Coordination Modes Established by the Hub Firm of an Innovation Network: The Case of an SME Bearer. *Journal of Small Business Management*, 50(2): 216-238.
Gardet, E., & Mothe, C. 2011. The Dynamics of Coordination in Innovation Networks. *European Management Review*, 8(4): 213-229.
Glänzel W, & Czerwon H.J. 1995. A new methodological approach to bibliographic coupling and its application to research-front and other core documents. *Proceedings of 5th International Conference on Scientometrics and Informetrics*, held in River Forest, IL, June 7-10, 167-176.
Glänzel W, & Czerwon H.J. 1996. A new methodological approach to bibliographic coupling and its application to the national, regional and institutional level. *Scientometrics*, 37(2). 195–221.
Hagedoorn, J., Cloodt, D., & van Kranenburg, H. 2005. Intellectual property rights and the governance of international R&D partnerships. *Journal of International Business Studies*, 36(2): 175-186.
Hanaki, N., Nakajima, R., & Ogura, Y. 2010. The dynamics of R&D network in the IT industry. *Research Policy*, 39(3): 386-399.
Helble, Y., & Chong, L. C. 2004. The importance of internal and external R&D network linkages for R&D organisations: evidence from Singapore. *R & D Management*, 34(5): 605-612.
Huang, H. C., Shih, H. Y., & Wu, Y. C. 2010. *Constructing National Innovative Capacity in Globalization: The Network Autocorrelation Perspective*. New York: Ieee.
Iwata, S., Kurokawa, S., & Fujisue, K. 2006. An analysis of global R&D activities of Japanese MNCs in the US from the knowledge-based view. *Ieee Transactions on Engineering Management*, 53(3): 361-379.
Jarneving B. 2007. Bibliographic coupling and its application to research-front and other core documents. *Journal of Informetrics*, 1(4), 287-307.
Johnson, W. H. A., & Medcof, J. W. 2007. Motivating proactive subsidiary innovation: Agent-based theory and socialization models in global R&D. *Journal of International Management*, 13(4): 472-487.
Kemp, R., Soete, L., & Weehuizen, R. 2012. *Towards an Effective Eco-Innovation Policy in a Globalised Setting*. Cheltenham: Edward Elgar Publishing Ltd.
Kessler M. M. 1963. Bibliographic coupling between scientific papers. *American Documentation*, 14(1), 10-25.
Konsti-Laakso, S., Pihkala, T., & Kraus, S. 2012. Facilitating SME Innovation Capability through Business Networking. *Creativity and Innovation Management*, 21(1): 93-105.

Kurokawa, S., Iwata, S., & Roberts, E. B. 2007. Global R&D activities of Japanese MNCs in the US: A triangulation approach. *Research Policy*, 36(1): 3-36.
Kwon, H. U. 2005. International R&D spillovers from Japanese to Korean manufacturing industry. *Hitotsubashi Journal of Economics*, 46(2): 135-147.
Laperche, B. 2008. *The Networked Enterprise in Innovation Networks and the Roles of Intellectual Property Rights*. Wuhan: Wuhan Univ Technology Press.
Lee, G. H. 2005. Direct versus indirect international R&D spillovers. *Information Economics and Policy*, 17(3): 334-348.
Lhuillery, S., & Pfister, E. 2011. Do Firms Know the Scope of their R & D Network? An Empirical Investigation of the Determinants of Network Awareness on French Survey Data. *Industry and Innovation*, 18(1): 105-130.
Li, D., Eden, L., Hitt, M. A., & Ireland, R. D. 2012. *Knowledge Management in International R&D Alliances a Cultural Perspective*. Charlotte: Information Age Publishing-Iap.
Li, J. T. 2010. Global R&D Alliances in China: Collaborations With Universities and Research Institutes. *Ieee Transactions on Engineering Management*, 57(1): 78-87.
Li, J. T., & Kozhikode, R. K. 2009. Developing new innovation models: Shifts in the innovation landscapes in emerging economies and implications for global R&D management. *Journal of International Management*, 15(3): 328-339.
Li, J. T., & Xie, Z. Z. 2011. Global R&D Strategies in an Emerging Economy: The Development and Protection of Technological Competencies. *European Management Review*, 8(3): 153-164.
Li, J. T., & Yue, D. R. 2005. Managing global research and development in China: Patterns of R&D configuration and evolution. *Technology Analysis & Strategic Management*, 17(3): 317-337.
Li, Y. P., Wu, S. T., & Gao, F. 2009. A Study on Effect of Talent Cultivation in Innovation Network of Multinational Corporations. In H. Gu, Z. Zhang, T. J. Wong, & J. Chen (Eds.), *Icoscm 2009 - Proceedings of the 3rd International Conference on Operations and Supply Chain Management*, Vol. 3: 823-827. Wuhan: Chinese Univ Hong Kong, Economics & Mangement School, Wuhan Univ.
Libaers, D., & Meyer, M. 2011. Highly innovative small technology firms, industrial clusters and firm internationalization. *Research Policy*, 40(10): 1426-1437.
Liu, J. J., Wang, Y., & Zheng, G. 2010. Driving forces and organisational configurations of international R&D: the case of technology-intensive Chinese multinationals. *International Journal of Technology Management*, 51(2-4): 409-426.
Marcone, M. R. 2012. SMEs and the internationalisation of R&D activities: knowledge transfer flows between firms. *European Journal of International Management*, 6(2): 133-153.
Martinez-Noya, A., Garcia-Canal, E., & Guillen, M. F. 2012. International R&D service outsourcing by technology-intensive firms: Whether and where? *Journal of International Management*, 18(1): 18-37.
Matlay, H., & Mitra, J. 2004. *Learning, innovation and globalization: the competitive advantage of collaborative entrepreneurship*. Cheltenham: Edward Elgar Publishing Ltd.
Melia, M. R., Perez, A. B., & Dobon, S. R. 2010. The influence of innovation orientation on the internationalisation of SMEs in the service sector. *Service Industries Journal*, 30(5): 777-791.

Mendez, A. 2003. The coordination of globalized R&D activities through project teams organization: an exploratory empirical study. *Journal of World Business*, 38(2): 96-109.
Nagasato, K., & Tanabe, K. 2007. *A study of globalization of research and development - Innovation management in China*. Wuhan: Wuhan Univ Technology Press.
Niosi, J. 1999. The Internationalization of Industrial R&D - From technology transfer to the learning organization. *Research Policy*, 28(2-3): 107-117.
O'Cass, A., & Weerawardena, J. 2009. Examining the role of international entrepreneurship, innovation and international market performance in SME internationalisation. *European Journal of Marketing*, 43(11-12): 1325-1348.
Owen-Smith, J., & Powell, W. W. 2004. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science*, 15(1): 5-21.
Oxley, J. E., & Sampson, R. C. 2004. The scope and governance of international R&D alliances. *Strategic Management Journal*, 25(8-9): 723-749.
Pavlinek, P. 2012. The Internationalization of Corporate R&D and the Automotive Industry R&D of East-Central Europe. *Economic Geography*, 88(3): 279-310.
Pekkarinen, S., & Harmaakorpi, V. 2006. Building regional innovation networks: The definition of an age business core process in a regional innovation system. *Regional Studies*, 40(4): 401-413.
Persson, O. 1994. The intellectual base and research front of JASIS 1986–1990. *Journal of the American Society for Information Science*, 45(1), 31-38.
Pilkington A., Meredith J, 2009, The evolution of the intellectual structure of operations management—1980–2006: A citation/co-citation analysis, *Journal of Operations Management*, 27, 185-202.
Qi, Y., Wu, X. B., & Liu, X. F. 2007a. *Flexible strategy built on modular innovation networks*. Hangzhou: Zhejiang Univ Press.
Qi, Y., Wu, X. B., Wang, W. B., & Tang, L. L. 2007b. *MNC-SMEs alliance and modular synergic innovation on global dynamic modular innovation network*. Chengdu: Sichuan Univ Press.
Ramos-Rodriguez A.R. and Ruiz-Navarro J, 2004. Changes In The Intellectual Structure Of Strategic Management Research: A Bibliometric Study Of The Strategic Management Journal, 1980–2000; 25: 981-1004.
Riccaboni, M., & Moliterni, R. 2009. Managing technological transitions through R&D alliances. *R & D Management*, 39(2): 124-135.
Riccaboni, M., & Pammolli, F. 2003. Technological regimes and the evolution of networks of innovators. Lessons from biotechnology and pharmaceuticals. *International Journal of Technology Management*, 25(3-4): 334-349.
Richards, M., & Yang, Y. 2007. Determinants of foreign ownership in international R&D joint ventures: Transaction costs and national culture. *Journal of International Management*, 13(2): 110-130.
Rodriguez, A., & Nieto, M. J. 2010. Cooperation and Innovation in The Internationalisation of Knowledge-Intensive Business Services. In J. PlaBarber, & J. Alegre (Eds.), *Reshaping the Boundaries of the Firm in an Era of Global Interdependence*, Vol. 5: 247-270. Bingley: Emerald Group Publishing Ltd.
Salavisa, I., Sousa, C., & Fontes, M. 2012. Topologies of innovation networks in knowledge-intensive sectors: Sectoral differences in the access to knowledge and complementary assets through formal and informal ties. *Technovation*, 32(6): 380-399.

Schiffauerova, A., & Beaudry, C. 2012. Collaboration spaces in Canadian biotechnology: A search for gatekeepers. *Journal of Engineering and Technology Management*, 29(2): 281-306.
Sci2 Team, 2009, *Science of Science (Sci2) Tool*. Indiana University and SciTech Strategies. Retrieved from http://sci.slis.indiana.edu.
Sedita, S. R., Belussi, F., & Fiscato, G. 2011. What Lies beneath the Internationalization of Firms In A Regional Innovation System? In C. G. Asmussen, T. Pedersen, T. M. Devinney, & L. Tihanyi (Eds.), *Dynamics of Globalization: Location-Specific Advantages or Liabilities of Foreignness*, Vol. 24: 299-326. Bingley: Emerald Group Publishing Ltd.
Semitiel-Garcia, M., & Noguera-Mendez, P. 2012. The structure of inter-industry systems and the diffusion of innovations: The case of Spain. *Technological Forecasting and Social Change*, 79(8): 1548-1567.
Sener, F., & Zhao, L. X. 2009. Globalization, R&D and the iPod Cycle. *Journal of International Economics*, 77(1): 101-108.
Shapira, P., Youtie, J., & Kay, L. 2011. National innovation systems and the globalization of nanotechnology innovation. *Journal of Technology Transfer*, 36(6): 587-604.
Shen, Y. H., & Wang, H. S. 2006. *To improve the performance of SMEIN: An effective way for TSMEs' growth*. Marrickville: Orient Acad Forum.
Small, H., 1973. Co-citation in the scientific literature: a new measure of the relationship between two documents. *Journal of the American Society for Information Science*, 24, 265-269.
Song, J., Asakawa, K., & Chu, Y. 2011. What determines knowledge sourcing from host locations of overseas R&D operations?: A study of global R&D activities of Japanese multinationals. *Research Policy*, 40(3): 380-390.
Soofi, A. S., & Ghazinoory, S. 2011. The network of the Iranian techno-economic system. *Technological Forecasting and Social Change*, 78(4): 591-609.
Tsai Wenpin, Wu Chia-hung, 2010. Knowledge Combination: A Cocitation Analysis, *Academy of Management Journal*, 53(3), 441-450.
Tian, H., & Zhang, X. W. 2007. *Types of regional innovation systems and innovation policy in China*. Hangzhou: Zhejiang Univ Press.
van Beers, C., Berghall, E., & Poot, T. 2008. R&D internationalization, R&D collaboration and public knowledge institutions in small economies: Evidence from Finland and the Netherlands. *Research Policy*, 37(2): 294-308.
van der Valk, T., Chappin, M. M. H., & Gijsbers, G. W. 2011. Evaluating innovation networks in emerging technologies. *Technological Forecasting and Social Change*, 78(1): 25-39.
Verburg, R. M. 2007. Managing Knowledge in Organizational Networks of Innovation - Strategies & Practices. In P. Cunningham, & M. Cunningham (Eds.), *Expanding the Knowledge Economy: Issues, Applications, Case Studies, Pts 1 and 2*, Vol. 4: 947-953. Amsterdam: Ios Press.
von Zedtwitz, M., Gassmann, O., & Boutellier, R. 2004. *Organizing global R&D: Challenges and dilemmas*. Amsterdam: Elsevier Science Bv.
Wang, W. L., Liu, Y., & Sun, G. J. 2010. *The Analysis and Implementation Strategies on Operation Model of University-Enterprise Cooperative Innovation Network*. Wuhan: Wuhan Univ Technology Press.
White, H., Griffith, B.C., 1981. Author co-citation: a literature measure of intellectual structure. *Journal of the American Society for Information Science*, 32, 163-171.

White, H.D., McCain, K., 1998. Visualizing a discipline: an author cocitation analysis of information science, 1972–1995. *Journal of the American Society for Information Science*, 49, 327-355.
Wu, F. S. 2007. Internationalisation of research and development: the case of Taiwanese firms. *International Journal of Technology Management*, 39(3-4): 297-310.
Wu, X. B., Qi, Y., & Sheng, L. L. 2007. *Modular innovation, dynamic modular innovation networks and global synergic innovation mechanism connecting MNCs with SMEs*. Cambridge: Univ Cambridge, Inst Manufacturing.
Wuebker, R., Acs, Z. J., & Florida, R. 2010. *The Globalization of Innovation and Entrepreneurial Talent*. New York: Springer.
Yoichi, S. 1991. *Global R&D management in the electronics industry : a comparative study between U.S. and Japanese multinationals*. Thesis (M. S.), Massachusetts Institute of Technology, Boston, USA.
Yu, G. B. 2006. *University sci-tech innovation platform: A new mode of industry-academic links*. Wuhan: Wuhan Univ Technology Press.
Yu, K. J. 2007. *A new idea for the research on cluster innovation network system model-based on the view of the use and creation of social capital*. Marietta: American Scholars Press.
Yu, X. Y., & Si, S. 2012. Innovation, internationalization and entrepreneurship: A new venture research perspective. *Innovation-Management Policy & Practice*, 14(4): 524-539.
Zahra, S. A., Ucbasaran, D., & Newey, L. R. 2009. Social knowledge and SMEs' innovative gains from internationalization. *European Management Review*, 6(2): 81-93.
Zhang, Y. N., & Chen, L. 2006. *Beyond the linear innovation process model: A case study of Manchester Science Park*. Alfred: Alfred Univ.
Zhang, Y. N., Chen, L., & Yu, G. B. 2007. *Innovation network: The new role of UK science parks*. Wuhan: Wuhan Univ Technology Press.
Zhaohua, W., & Jianhua, Y. 2007. *Research on operation modes of outsourcing innovation network*. Hangzhou: Zhejiang Univ Press.
Zhou, L. J., Fan, Q. Y., & Du, Y. W. 2007. *Study on countermeasures to improve independent innovation capacity of private enterprises - Based on the viewpoint of standardization*. Marietta: American Scholars Press.
Zhu, L., & Jeon, B. N. 2006. *International R&D Spillovers: Trade, FDI, and Information Technology as Spillover Channels*. Seoul: Korea Development Inst.
Zhu, L., & Jeon, B. N. 2007. International R&D Spillovers: Trade, FDI, and Information Technology as Spillover Channels. *Review of International Economics*, 15(5): 955-976.

Promoting innovation by disruptive networks:
Learning from the high-tech industry?

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Abstract
This paper examines development networks in the field of electric mobility. It is argued that the replacement of internal combustion engine disrupts existing supply chains and leads to the emergence of networks to overcome the OEM's loss of information superiority. As the situation of widely dispersed knowledge is comparable to the setting of more science-driven industries, it is hypothesised that the findings of research on high-tech networks are transferable. Based on a systematic review and established methods of qualitative research two multi-dimensional models have been developed to capture correlations between the network design and its innovativeness. The datasets of two comparative case studies are used allowing us to test for the transferability of literature-derived causalities, with interesting results: we found support for our hypotheses that network practices of the high-tech industries also outperform in terms of innovation in the disrupted setting of electric vehicle development.

Keywords: innovation networks, disruptive innovations, vehicle development, innovation measurement, network performance

1. Introduction

Transition has always been vital in the economic and technical history (Schumpeter & Opie 1934). It yields to improvements in technological progress and welfare. Chandler (1962) argues that a company represents the organisational answer to opportunities and threats arising from changing environments. Thus, changes of the framework go with challenges for the current players within the industry. While in weakly innovative industries well-established structures like leaderships can persist for a long time, other industries are more likely to witness a disruptive innovation, possibly causing a reset of an entire branch and the vital need for modify the organization (Christensen 1997).

Although so far the automotive industry has not been known for being unstable, electric mobility is one of the technologies having the potential to reform the industry (Kampker et al. 2013a). However, the long-term market penetration of electric mobility is still questioned and it has yet to be proved whether an “extendable core” exists. According to Wessel and Christensen (2013, p. 22) this concept defines the essential function of a disruptive innovation “that allows the disrupter to maintain its performance advantage as it creeps upmarket in search of more and more customers”. Investing billions of euro carmakers illustrate their expectation that the technology possesses an extendable core and will achieve significance in the automobile portfolio within the next decades. These massive investments indicate that the companies anticipate a transition from the niche existence of electric mobility to a down-market product. This rearrangement of the industry is certainly not going to happen overnight. Even optimistic scenarios predict the continued dominance of the internal combustion engine (ICE) technology for at least the next decade (Propfe et al. 2013).

While the mass market potential is still unclear, the changes involved are already obvious. A new market is to be created which differs significantly from the current one. In the automotive industry there is no historical precedent for a comparable shift in technology, competences and corresponding competitive conditions (Thomes 2013). The OEMs’ present-day main sphere of activities comprises internal combustion engine development, system integration, design, brand management and marketing of the final product. With the progression of the replacement of internal combustion engines as the centrepiece of cars, the car manufacturers will lose a main pillar of their nowadays business, which consequently will lead to either shrinking or expansion to new fields of activity (Kasperk et al. 2012).

Being in this period of transition the automotive industry finds itself in a situation of multi-market competition. Automotive companies compete with each other within the new technology of alternative powertrains and simultaneously within the established technology which will stay an adequate option for people’s mobility needs. Firms are obliged to innovate in this highly uncertain and competitive setting in which being a year ahead in development can create significant competitive advantage. Entry barriers prove significantly lower than in the traditional market which enables start-ups to challenge established OEMs. Complexity and diversity of necessary knowledge as well as the technological uncertainty is rising to a new level as traditional technology is enhanced by the new components of electric vehicles. According to Powell & Grodal (2005) proactive commitment to networking activities allows one to speed up the access to knowledge, facilitates its transfer and its recombination in these shifted framework conditions.

Literature investigates such settings mainly for high-tech or bio-tech industries and identifies a “large-scale reliance on inter-organisational collaborations“ (Powell et al. 1996, p. 116) observing an upsurge of networks, when knowledge is widely dispersed and the focal firm lacks information superiority (Müller et al. 2013, p. 13ff.). In several cases research reveals a significant relation between collaborations and the innovation performance of firms (Phelps et al. 2012). These observations motivate us to explore the innovation effect of networks on the current technological trend of electrified powertrains. In addition, a recent study of the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University shows that the majority of surveyed managers of OEMs and Tier-1s believe that networks can help to overcome the major problems of electric vehicle production (Kampker et al. 2013b).

For this purpose our multi-method paper analyses the effect of network designs on the innovative output of car development as it has been repeatedly confirmed in more science-driven industries like the high-tech industry. To reach this goal we conduct a systematic literature review, before we develop two multi-dimensional models to a) provide a suitable measurement of innovativeness in electric vehicle development (Innovation Performance Model) and b) integrate the core factors of network analysis (Network Performance Model). This methodology represents an enhancement of earlier analysis of innovation measurements which mostly rely on single statistics such as the number of patents.

A multi-case study method allows us to empirically confirm the results of the systematic literature review, which have shown validity only in high-tech industries, in the disruptive setting of electromobility. Two comparable electric vehicle developments have been studied which both grew out of German technical universities.

Applying the multi-dimensional models derived from the high-tech industry we find that one of the assessed projects outperforms regarding its network design and regarding its general innovation performance. Within the given assumptions these results support the notion that different network designs possessing some advantageous characteristics actually lead to different degrees of innovation performance. We thus find support for our hypotheses that the high-tech firms' networks could serve as a model for designing networks in cases of disruptive technologies like the development of electric vehicles.

Below, we survey theories on innovation measurement, on the innovation effect of networks and on the framework conditions of electric vehicle developments, outlining our hypotheses based on this literature. This section is followed by a discussion of the models developed and used in our study. The following section briefly describes our case studies' datasets and then presents the empirical results and a concluding discussion of their implications.

2. Theory

The present paper can be classified into the area of social network analysis, which is a relatively new research field and strongly shaped by US researchers, e.g. by Steven Borgatti. Up to today the research in networks lacks of uniform theoretical focus and corresponding methods (Stegbauer 2010). This should underline the present paper's purpose to contribute with a systematic access of literature and a case study validation approach bridging the gap between theory and practice.

During the last two decades social network analysis has started to play a dominant role in the explanation of several poorly-understood phenomena of organisms, individuals and organizations. Research on closely-knit complexes of relations and interactions reveals a set of network-immanent levers for performance such as organizational creativity or corporate success. On the one hand this emphasizes that explanatory approaches may not only be based on procedural or structural inner-firm peculiarities to understand e.g. outperformances (Borgatti et al. 2009, p. 892). On the other hand it clarifies that networking is more than a work-around for sharing R&D costs and risks of R&D, differentiating it from the main focus of prior research (Mowery 1988).

Accordingly networks have become one of the conceptual issues to understand the emergence of innovation. Smith (2005, p. 151) shows that networks can be the locus of innovation by relying “on collaboration and interactive learning, involving other enterprises, organizations, and the science and technology infrastructure”. Network characteristics are increasingly considered for the analysis of organizational innovation activities (Figure 1). Existing reviews reveal many quantitative and qualitative work which provide evidence of significant coherences between the design of networks and the frequency, intensity as well as relevance of innovations in development processes (Phelps et al. 2012, Borgatti et al. 2009, Becheikh et al. 2006, Powell & Grodal 2005, Hagedoorn 2002).

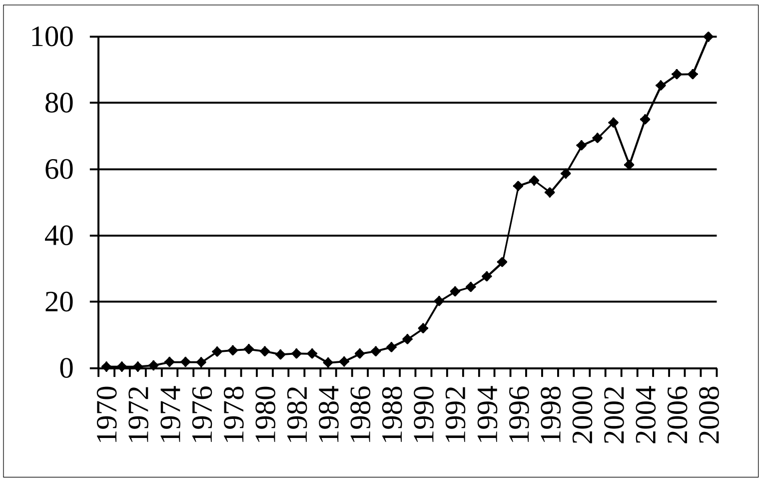


Figure 1: Relative occurrence of phrase “innovation network” in English-language publications between 1970-2008 (2008=100). Source: Google (2013)

This paper’s field of research is the automotive industry. The inquiry into the automotive industry’s networking dimension of innovation obviously is not a new field of research. According to Piller & Waringer (1999, pp. 93ff.) automotive OEMs are increasingly searching for partners with complementing capabilities to respond to several challenges which include rising complexity and frequency of product developments. Today neither the management of this complexity nor the provision of all necessary competences prove possible resulting in the search for cooperation with complementing capabilities so that an increasing number and intensity of inter-firm links between the OEM as the focal firm and different partners along every stage of the value chain can be observed (Schuh et al. 2010). This integration of suppliers in the OEM’s R&D-activities is well-covered in the literature (Reichwald et al. 2009, pp. 39f.). Garcia Sanz et al. (2007, pp. 124, 404) underpins the importance of the so called network competence, meaning the willingness and ability of suppliers to systematically and beneficially contribute to the OEMs network, rating it as a core competence in nowadays automotive business.

While the existence and necessity of those knowledge networks is well-covered on a qualitative level, quantitative findings about the correlations between network characteristics and the cooperative product development in the automotive industry are rare. Analysing the numbers of publications it becomes obvious that research focusses on knowledge-intensive industries (Müller et al. 2013). Powell & Grodal (2005), analysing various studies on knowledge networks in much science-driven industries, argue in their notable review that these industries are predestined to show an innovation effect of networks. Based on the empirical evidence that networks trigger the exchange of new ideas, simplify access to resources (e.g. innovative staff) and pool knowledge, the studies conclude that there is a significant correlation between the efficiency of a network and its innovativeness or better said – how it can be claimed for most of organizational research – "structure matters" (Fioretti 2012, p. 233). Also the more recent review of Phelps et al. (2012) should be particularly mentioned. The authors confirm the causalities derived by analysing numerous empirical studies on networks that are drawn from knowledge-intensive industries. These sectors again have a high R&D intensity and are more science-driven than the traditional automotive sector (Powell et al. 1996, p. 116). According to Rosenberg (1994, pp. 216f.) future development paths of such high-tech industries tend to be unpredictable instead of being strong path-dependent.

The lack of research in automotive networks might be the result of rare data insights or a too small samples size. But Powell's and Rosenberg's argument really matters here which points to the conclusion that a significant degree of coherence between network design and development performance is not expected to show validity in the automotive sector. The relevance and the necessity of acting in networks are regarded to be weaker in traditional production industries than it is the case for high-tech firms. Technical innovations certainly are key for competitive advantage but are less R&D-intensive, have fewer technical uncertainties and require fewer resources (Müller et al. 2013). In these settings knowledge is more concentrated in the automotive OEM's reach and thus not as widely dispersed as in high-tech innovation settings (Powell & Grodal 2005, p. 69).

While these considerations are made for established technologies like internal combustion engine (ICE), where the bulk of information is available and applicable for the strong focal firm, the relevant know-how for electric drivetrains is widely dispersed and is subject to uncertainty in the early stages of the new technology. This applies to both the product and the production processes (Kampker et al. 2012). As a response to this, networks in the automotive sector raise to a new level of importance and complexity (Brand & Herrmann 2012). There are two main reasons for this: First, established components are replaced or enhanced by new ones which need different product and process competences. The new technology calls for new disciplines for solving the core development problems. The need for chemical skills is one such prominent and crucial example that shapes performance characteristics for Li-Ion-Batteries as a centrepiece of an electric vehicle (Kampker et al. 2011). Secondly, there is a lot of empirical evidence that these skills cannot be found in the current network and that the design of networks is changing significantly (Kampker et al. 2013b). Hence, supply chain disruption goes hand in hand with network disruption. These new networks, which are characterized by weaker links than established partnerships, new links to much heterogeneous partners and unprecedented low barriers of entry, do not rely on the OEM's former information and coordination superiority and cause the actors to give up established networking patterns.

Based on the findings that networks are key in situations of highly scattered knowledge base and lack of information superiority of single players or an established clique, and that there are no considerable publications as to the innovative impact of automotive networks the hereby presented research find its contributions. The research question arising from these considerations is whether the network characteristics within these disrupted networks of the automotive industry have the same effect on a network's success in terms of innovative output as in the well-covered high-tech setting. The effort of empirically validating this coherence is key for the present paper.

3. Method

To test the above hypotheses, we applied a multi-method study taking a three-stage approach (Figure 2). We started with a systematic literature review as to the measurement of innovation and as to the effect of network characteristics on the innovativeness of collaborations **(step 1)**.

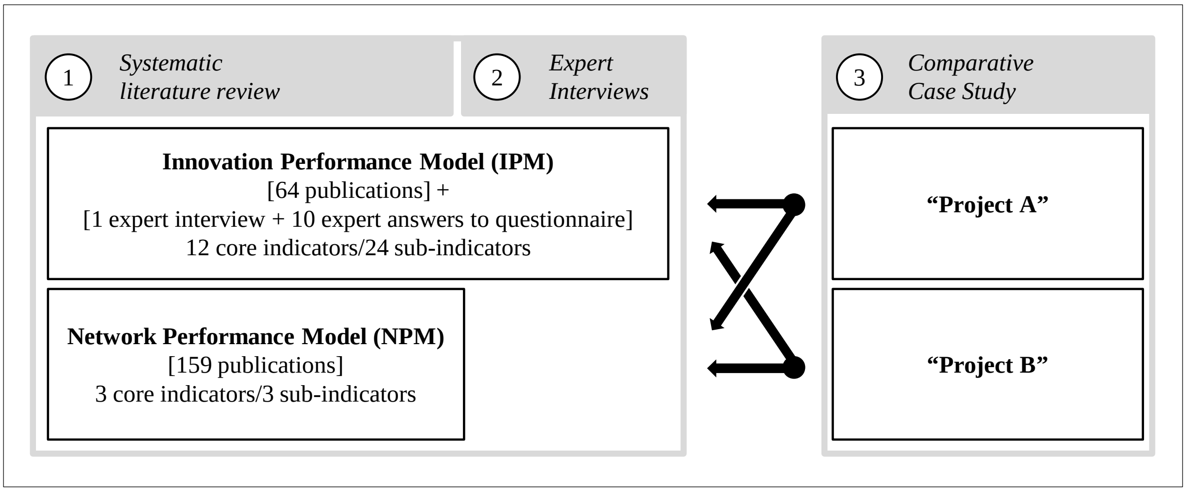


Figure 2: Research procedure, methods of qualitative research and datasets applied

First it is necessary to evaluate the innovation performance of product developments in an objective way. The multi-dimensional Innovation Performance Model (IPM) has been developed considering our idea of the Return on Engineering (RoE) as the target figure (Müller et al. 2013). Innovation or innovativeness is often used in a vague and contradictory way (Adams et al. 2006, p. 21). This is due to the fact that the complex, diversified activities of innovation are not directly quantifiable. The literature-based model has been developed to adequately assess a specific development on its actual return quantifying the observable criteria of the innovation inputs and outputs. This approach reduces systematic errors and legitimizes the development of our hypotheses.

This method has also been used to derive the second multi-dimensional model that is the correlations between network design and innovation, the so called Network Performance Model (NPM). The here reviewed literature additionally has been quantitatively analysed in a meta analysis. Doing this, the findings of a large number of individual studies has been mathematically integrated to put our model on a scientifically sound basis (Glass 1976). The Network Performance Model (NPM) performs two functions: First, the individual effect of a single network factor can be evaluated. Secondly, a model is created which allows for drawing conclusions from the network characteristics as to the extent of its innovation performance. These conclusions of course depend on the validity of the model in the investigated setting which is the objective of this work.

Again, it should be emphasized that the reviewed literature only considers science-driven industries and that it is thus the intention of this work to check the comparability of the network-derived innovativeness (Network Performance Model) and the actually measured innovativeness (Innovation Performance Model). If these both have equal patterns, our study results indicate that the findings in science-based industries as to the "optimal" network design may prove valid for this new setting which is the electric vehicle development in its early phase as it has been motivated in the previous section.

Innovation measures are much discussed in literature. Most frequently patents are used for a measure of innovation (Powell & Grodal 2005, p. 65). While this proxy for innovation seems to be suitable for science-driven industries and even here critically discussed and evaluated as too restrictive (Jaffe & Trajtenberg 2002, pp. 201 ff.), we argue that it is not adequate for assessing the development of a car in which patentable issues mostly incrementally contribute to the entire product system. Hence, we used expert interviews to do the necessary enhancements to our Innovation Performance Model (IPM) and to substantiate our idea of inadequacy of a limitation to patents as proxy for our setting **(step 2)**. Industry experts of eleven different electric vehicle development projects were then asked about their evaluation of the performance measurements. The result of this enhancement is a comprehensive model in which literature-derived causalities have not been altered in any way, but application is now possible to the new car development to provide the transferability of the results and a more application-oriented work.

Finally, we used a multiple-case study to get a comparative dataset **(step 3)** which is crucial to derive correlations. A single-case study, while it cuts down research efforts, lacks a reference and is thus not applicable in our context. To support relevance of findings the two cases analysed are comparable in the innovation object but much different in the network design and thus fulfil the requirements related to comparative study design. This procedure benefits the advantages of the applied comparative study which essentially is the improvement of empirical validation (Yin 2009, pp. 46-53, 150-151). Two cases have been investigated, both aiming at the development of a purpose-designed electric vehicle. We call these cases Project A and Project B. They were identified as suitable case studies for this research as both of them grew out of German technical universities. The car development is captured in a heterogeneous consortia network of several institutional and corporate partners. The cases are comparable as to the university origin, main objectives and other initial conditions. Both projects started in the same year. This framework allows us to focus on the networking dimension of innovation which substantially differs between projects.

Figure 2 gives a first impression about the data used for our multi-method study. In the first stage our broad literature search identified 64 scientific publications to define the Innovation Performance Model (IPM) and 159 publications to develop the Network Performance Model (NPM). The corresponding publications are listed in Table 1 for IPM respectively Table 2 for NPM. In the second stage, the model enhancement, a questionnaire with a Likert-scale (1 to 10), was used to provide the applicability of the IPM to the electric vehicle development. The survey was conducted during a conference workshop of representatives of eleven different electric vehicle development projects. Representing a significant number of European initiatives, this supports the quality and relevance of answers which were further considered in the course of the investigation. The last stage is then characterized by a multitude of data sources to cover all the identified quantifiable measures of innovation and network characteristics for our econometric models.

Hereinafter, the quantitative models, used in this study, are presented. Applied to the two cases they constitute a well-founded basis for the deduction of our findings in the results section.

Innovation Performance Model (IPM)

The Innovation Performance Model (IPM), assessing the Return on Engineering (RoE) of the projects A and B, forms a ratio between their respective innovation output and innovation input. A normalisation results in two relative values for Project A and Project B and thus allows for facile comparability.

$$RoE\ (p) = \frac{Innovation\ \ Output\ (p)}{Innovation\ \ Input\ (p)} \qquad for\ \ p \in \{A; B\} \tag{1}$$

Innovation output and innovation input represent sums of the weighted, normalised parameter values of innovation output indicators and innovation input indicators.

$$Innovation\ \ Output\ (p) = \sum_{1}^{m} \alpha_j \left(I_{Out,j}(p)\right)_{norm} \tag{2}$$

$$Innovation\ \ Input\ (p) = \sum_{1}^{n} \beta_i \left(I_{In,i}(p)\right)_{norm} \tag{3}$$

$\alpha_j; \beta_i \in [0;1]$ = Weighting factor output indicator j; input indicator i

$I_{Out,j}; I_{In,i}$ = Parameter value output indicator j; input indicator i

$m; n$ = Total number of output indicator j; input indicator i

The normalisation procedure concerning the output indicator parameter values for Project A is depicted below. The project exhibiting the superior specific parameter value is assigned the value one (100%), whereas the other project is relatively evaluated (x%).

$$\left(I_{Out,j}(A)\right)_{norm} = \frac{I_{Out,j}(A)}{\max\left(I_{Out,j}(A); I_{Out,j}(B)\right)}$$
$$\left(I_{Out,j}(A)\right)_{norm} = 0 \qquad for \quad I_{Out,j}(A) = I_{Out,j}(B) = 0 \tag{4 a. – b.}$$

$(I_{Out,j}(A))_{norm}$ = Normalised parameter value output indicator j for A

$I_{Out,j}(A)$ / $I_{Out,j}(B)$ = Parameter value output indicator j for A / B

The parameter values of the indicators can either be directly measured or constitute aggregated values. Aggregation across weighted sub-indicators leads to the value I_{Aggr}.

$$I_{Aggr} = \sum_{1}^{q} \gamma_r \left(I_{Sub,r}\right)_{norm} \tag{6}$$

I_{Aggr} = Parameter value aggregated indicator

q = Total number of sub-indicators r

$\gamma_r \in [0;1]$ = Weighting factor normalised sub-indicator r

$I_{Sub,r}$ = Parameter value sub-indicator r

The weighting factor γ_r is determined through a literature assessment and the expert estimation according to the interview material.

$$\gamma_r = 0{,}1\left(\sum_{1}^{p} e_{Lit,l}\right) + (1 - 0{,}1p)e_{Int}$$

$$\gamma_r = \frac{1}{p}\sum_{1}^{p} e_{Lit,l} \qquad \textit{for} \quad e_{Int} = \{\ \}$$

$$\gamma_r = 0 \qquad \textit{for} \quad e_{Int} = 0$$

(7 a. – c.)

e_{Lit}, $e_{Int} \in [0;1]$ = Estimation literature, interview

The weighting factors α_j and β_i of innovation output and input determine the sensitivity of the result Return on Engineering (RoE) towards a variation of the indicator observed. Due to their pronounced significance the factors were investigated in detail. A multi-dimensional approach was chosen to include the assessments of literature, and expert estimations according to the interview and questionnaire. As shown for factor α_j below, five cases are distinguished.

$$\alpha_j = \frac{1}{3}\frac{1}{p}\sum_{1}^{p} e_{Lit,l} + \frac{1}{3}e_{Int} + \frac{1}{3}e_{Fr} \qquad \textit{for} \quad e_{Int} \in [0{,}1;1] \wedge p \geq 5$$

$$\alpha_j = \frac{1}{15}\sum_{1}^{p} e_{Lit,l} + \left(\frac{2}{3} - \frac{1}{15}p\right)e_{Int} + \frac{1}{3}e_{Fr} \qquad \textit{for} \quad e_{Int} \in [0{,}1;1] \wedge p < 5$$

$$\alpha_j = \frac{1}{3}\frac{1}{p}\sum_{1}^{p} e_{Lit,l} + \frac{2}{3}e_{Fr} \qquad \textit{for} \quad e_{Int} = \{\ \}$$

$$\alpha_j = e_{Fr} \qquad \textit{for} \quad e_{Int} = \{\ \} \wedge p = 0$$

$$\alpha_j = 0 \qquad \textit{for} \quad e_{Int} = 0$$

(5 a. – e.)

e_{Lit}, e_{Int}, $e_{Fr} \in [0;1]$ = Estimation literature, interview, questionnaire

The model set up is a multi-dimensional calculation concept of the relative innovation performance of Project A and Project B. The aim is to benefit from the advantages that the different indicators provide and to limit their shortcomings at the same time. The aggregation of similar sub-indicators to aggregated indicators counters the problematic of redundancy. This measurement strategy yields a meaningful estimation of the relative degree of innovation of the two projects. The resulting innovation indicators are presented in Table 1.

Table 1: Indicators, weightings and literature references for IPM

Cat.	***Indicator***	***Wgt***	***Literature reference***
Output indicators	Patents (aggr.)	0.41	Adams et al. 2006, p. 29; Becheikh et al. 2006, p. 649; Flor & Oltra 2004, p. 335; Grupp 1997, pp. 116ff.; Hagedoorn & Cloodt 2003, p. 1368; Kleinknecht et al. 2002, pp. 112f.; Powell et al. 1999, pp. 6, 14); Rogers 1998, pp. 11ff.; Smith 2005, pp. 158ff.
	Patents granted (sub-ind.)	0.4	
	Trade marks, designs (…)	0.3	
	Patent applications	0.4	
	Patent quotations	0.57	Flor & Oltra 2004, pp. 326f.; Hagedoorn & Cloodt 2003, p. 1369
	Scientific publications (aggr.)	0.53	Grupp 1997, pp. 174ff.
	Reference (WISO-NET)	0.5	

	Reference (GOOGLE-SCHOLAR)	0.5	
	Citation analysis	0.45	Grupp 1997, pp. 176f.
	Public interest (aggr.)	0.73	Becheikh et al. 2006, p. 650; Flor & Oltra 2004, pp. 327f.; Grupp 1997, pp. 177f.; Kleinknecht et al. 2002, pp. 115f.
	Journals (WISO-NET)	0.7	
	GOOGLE-Clicks	0.6	
	FACEBOOK-Likes	0.3	
	YOUTUBE-Clicks	0.3	
	Fair appearances	0.4	
	Project progress	0.63	---
	Reference (WISO-NET)	0.5	
	Reference (GOOGLE-SCHOLAR)	0.5	
	Citation analysis	0.45	
	Journals (WISO-NET)	0.7	
	GOOGLE-Clicks	0.6	
	FACEBOOK-Likes	0.3	
	YOUTUBE-Clicks	0.3	
	Fair appearances	0.4	
	Expert Evaluation	0.75	Becheikh et al. 2006, p. 649; Flor & Oltra 2004, p. 327; Kleinknecht et al. 2002, pp. 116f.
	Technological innovation	0.8	
	Professionalism public appearance	0.5	
	Evaluation project members	0.61	Becheikh et al. 2006, p. 650; Flor & Oltra 2004, pp. 327, 334; Grupp 1997, p. 196; Rogers 1998
	Commercial success	0.32	Adams et al. 2006, p. 37; Grupp 1997, p. 198; Powell et al. 1999, p. 15; Rogers 1998, p. 10
	Turnover	0.1	
	Orders signed	0.1	
	Units sold	0.1	
	Product properties	0.81	Grupp 1997, pp. 101ff.
	Max. reach	0.0	
	Min. price	0.6	
	Min. empty load	0.3	
	Max. speed	0.0	
	Acceleration 0-60 km/h	0.0	
	Max. vehicle payload	0.6	
	Product/Process intensity	0.5	Flor & Oltra 2004, p. 329; Grupp 1997, p. 113; Hagedoorn & Cloodt 2003, p. 1369
	Number of prototypes	0.0	
	Number of techn. derivates	0.4	
	Number of product announcem.	0.27	
	Closeness to series production	0.9	---
Input Ind.	Total invest	0.75	Adams et al. 2006, p. 27; Kleinknecht et al. 2002, pp. 113f.
	Personnel indicator	0.77	Adams et al. 2006, p. 27; Flor & Oltra 2004, p. 325; Grupp 1997, pp. 149f.; Kleinknecht et al. 2002, pp. 110ff.
	R&D personnel indicator	0.6	
	Number of employees	0.0	
	Education of employees	0.5	
	Project duration	0.59	---

Network Performance Model (NPM)

Just as in the case of the IPM the Network Performance Model (NPM) follows a multi-dimensional approach that takes into account the weighted parameter values of all identified network factors.

$$\text{Network Performance}(p) = \sum_{1}^{n} \delta_i \left(NF_i(p)\right)_{norm} \tag{8}$$

$\delta_i \in [-1;1]$ = Weighting factor network factor i

NF_i = Parameter value network factor i

n = Total number of network factors i

As mentioned above, the normalisation, which is also employed in this model, permits a comparison of the respective "Network Performance" measures. The weighting factors δ_i determine the sensitivity of the target value towards a change of the parameter value NF_i. In case of the NPM, the factors can take on negative values for a negative correlation between network factor and "Network Performance".

$$\delta_i = \sum_{j}^{m} w_j \varepsilon_{Lit,j} \tag{9}$$

w_j = Weighting factor estimation literature reference j

$\varepsilon_{Lit,j} \in [-1;1]$ = Estimation literature reference j

m = Total number of literature references

The use of the weighting factor w_j regarding the estimation of literature reference j (mostly review papers) takes into account the varying quantities of empirical studies they are based on. The bigger the number of primary studies investigated in the review papers the higher the weight of their findings.

$$w_j = \frac{n_{j,tot}}{n_{i,tot}} \tag{10}$$

$n_{j,tot}$ = Total number of studies considered in literature reference j

$n_{i,tot}$ = Total number of studies dealing with network factor i

The significance of the weighting factors δ_i are determined via a meta-analysis. This analysis evaluates the literature references regarding each network factor $\varepsilon_{Lit,j}$ systematically and quantitatively and thus provides a well-founded model. The estimations of the literature references $\varepsilon_{Lit,j}$ regarding the correlation between "Network Performance" and network factor i are derived from the investigated studies' results, respectively.

$$\varepsilon_{Lit,j} = \frac{1 \times n_{j,pos} + 0 * n_{j,neutr} - 1 * n_{j,neg}}{n_{j,ges}} \qquad for \quad \varepsilon_{Lit,j} = aggr.$$

$$\varepsilon_{Lit,j} = 1 \qquad for \quad \varepsilon_{Lit,j} = pos. \qquad (11\text{ a. – d.})$$

$$\varepsilon_{Lit,j} = 0 \qquad for \quad \varepsilon_{Lit,j} = neutr.$$

$$\varepsilon_{Lit,j} = -1 \qquad for \quad \varepsilon_{Lit,j} = neg.$$

$n_{j,pos}$ = Number of positive evaluations as analysed by literature reference j

$n_{j,neutr}$ = Number of neutral evaluations as analysed by literature reference j

$n_{j,neg}$ = Number of negative evaluations as analysed by literature reference j

A value for $\varepsilon_{Lit,j}$ is determined through the division of the number of positive, neutral and negative, each multiplied with a corresponding factor of *+1; 0; -1* and the total number of primary sources investigated in that review (11 a.). In case of a direct evaluation without reference to another paper, the respective values are taken into account directly (11 b. – d.). Table 2 summarizes the resulting network factors.

Table 2: Factors, weightings and literature references for NPM

Network factor	***Wgt***	***Literature reference + ($\varepsilon_{Lit,j}$/ w_j)***
Number of network partners	0.56	Powell & Grodal 2005, p. 78 *(1/0.11)*; Powell et al. 1999, p. 14 *(1/0.11)*; Powell et al. 2012, p. 442 *(1/0.11)*; Phelps et al. 2012, p. 1131 *(0.2/0.56)*; Borgatti and Li 2009, p. 5 *(1/0.11)*
Centrality	0.75	Powell & Grodal 2005, pp. 65f. *(1/0.09)*; Whittington et al. 2009, pp. 93ff. *(1/0.18)*; Powell et al. 1999, pp. 4–24 *(1/0.05)*; Powell et al. 2012, p. 439 *(1/0.14)*; Phelps et al. 2012, pp. 1131, 1138 *(0.73/0.5)*; Borgatti and Li 2009, p. 5 *(1/0.05)*
Degree of locality	0.82	Powell & Grodal 2005, p. 66 *(0.33/0.07)*; Whittington et al. 2009, pp. 90ff., 115 *(1/0.5)*; Becheikh et al. 2006, pp. 657f. *(0.43/0.15)*; Powell et al. 2012, pp. 436, 444 *(1/0.13)*; Phelps et al. 2012, pp. 1132f., 1147 *(0.5/0.11)*; Borgatti and Li 2009, p. 5 *(1/0.04)*
Degree of heterogeneity	0.69	Powell & Grodal 2005, pp. 59f., 66f., 74 *(1/0.31)*; Powell et al. 1999, pp. 10f., 25 *(0/0.03)*; Adams et al. 2006, p. 27 *(1/0.03)*; Powell et al. 2012, pp. 438f, 444 *(1/0.19)*; Phelps et al. 2012, pp. 1131ff. *(0.1/0.31)*; Davis and Eisenhardt 2011, p. 163 *(1/0.13)*
Tie strength	0.55	Powell & Grodal 2005, pp. 62ff. *(0.2/0.23)*; Adams et al. 2006, pp. 36f. *(1/0.18)*;Phelps et al. 2012, pp. 1133f., 1147 *(0.55/0.59)*

Elaborating two comparable case study samples, which are presented in the following results section, the present study seeks to find support for the notion that the derived correlations between structure and performance could also improve automotive managerial practices by being applicable and beneficial in the innovation races of nowadays automotive business.

4. Results

The aim of this chapter is the evaluation of the projects A and B based on the models set up in the method section. It is expected that a comparison of the case study results for the Innovation Performance Model and Network Performance Model supports the idea that network factors in electromobility have a comparable effect on innovation performance as in the high-tech industry.

The IPM seeks to state the actual, relative innovation performance of the two projects by assessing their parameter values regarding each of the innovation indicators defined. The procedure is to be exemplarily shown by elaborating the output indicators *citation analysis* and *public interest* and the input indicator *project duration*.

Citation analysis. The analysis of citations reflects the number of quotations of the scientific articles published on the projects' basis. Both Project A and Project B have their source in the academic environment. Various scientific articles from the respective universities use the projects as an empirical validation basis of theoretical concepts. The investigation of the number of articles referring to these publications provides information regarding their impact or significance and is thus used as one proxy for innovativeness of the project. A Google Scholar search was employed to assess the total number of citations regarding the two projects. Over a period of two months this process was repeated on a weekly basis yielding an average number of 10.4 articles quoting publications from Project A's surrounding versus 5,7 referring to publications dealing with Project B. Using formula (4 a.) normalised values of $(I_{Out,j}(A))_{norm} = 1$ and $(I_{Out,j}(B))_{norm} = 0.55$ are deduced (see Table 3 below).

Public interest. The aggregated indicator *public interest* measures the degree of innovation via the consideration of the weighted sub-indicators mentioned in Table 1: *journals (WISO-NET), Google-Clicks, Facebook-Likes, Youtube-Clicks and fair appearances.* The aggregation is conducted according to formula (6). All of the sub-indicators depict so called innovation counts. Just like the indicator *citation analysis* they assess the number of – in the case of *journals (wiso-net)* – journals listed in the database *wiso-net* referring to the respective project – or in the case of *Google-Clicks* – the amount of search results and so on. The indicator *public interest* is similar to direct indicators assessing a products popularity through the investigation on journal advertising leading to a similar, positive weight of 0.73 (Flor & Oltra 2004).

Project duration. The indicator *project duration* is employed to account for varying efforts put into the respective project as a result of different time horizons. Both projects were launched in the same year and quarter. Consequently, the normalised values are both equal one.

The Return On Engineerung (RoE) representing the actual degree of innovation of Project A and B is calculated via formula (1) and produces the results: 100% (A) 82,9% (B).

Table 3: Results of Innovation Performance Model (IPM)

Cat.	Indicator	Wgt	Project A $(I_{Out,j}(A))_{norm}$	Project B $(I_{Out,j}(B))_{norm}$
Output indicators	Patents (aggr.)	0.41	0	0
	Patent quotations	0.57	0	0
	Scientific publications (aggr.)	0.53	1	0.89
	Citation analysis	0.45	1	0.55
	Public interest (aggr.)	0.73	1	0.73
	Project progress	0.63	1	0.78
	Expert Evaluation	0.75	1	0.89
	Evaluation project members	0.61	n/a*	n/a*
	Commercial success	0.32	1	0
	Product properties	0.81	1	0.75
	Product/Process intensity	0.5	1	0.5
	Closeness to series production	0.9	n/a*	n/a*
	Innovation Output		***4.72***	***3.26***

Cat.	Indicator	Wgt	$(I_{In,j}(A))_{norm}$	$(I_{In,j}(B))_{norm}$
Input Indic.	Total invest	0.75	1	0.58
	Personnel indicator	0.77	1	0.96
	Project duration	0.59	1	1
	Innovation Input		***2.11***	***1.76***

	Project A	Project B
Return on Engineering	**2.24**	**1.85**
(Return on Engineering)$_{norm}$	**100%**	**82,9%**

* indicators set to n/a could not be obtained and thus been excluded from the calculation

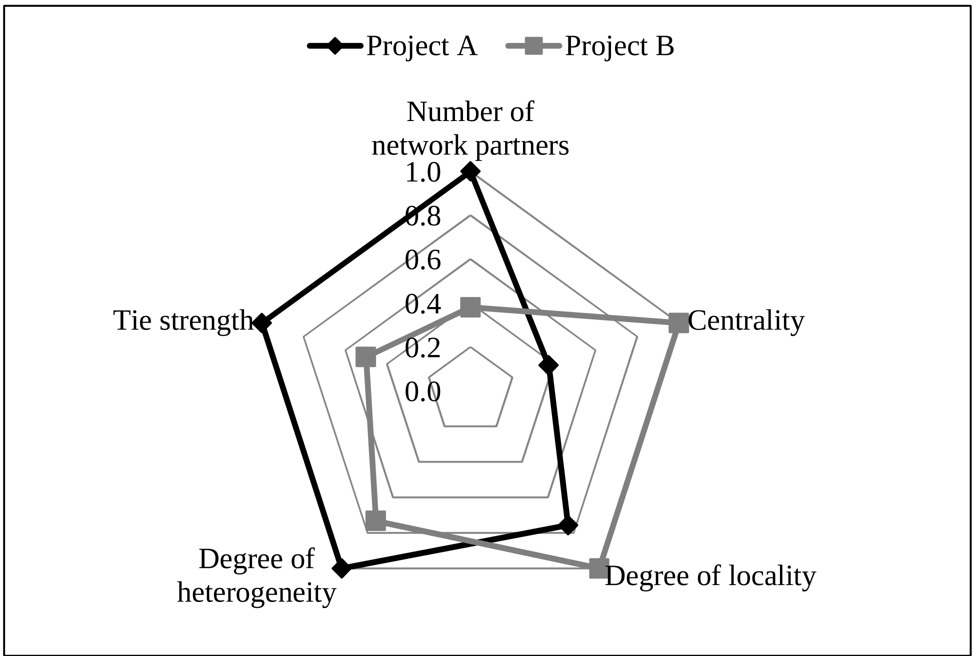
The Network Performance Model was established to estimate the projects' theoretical innovation performance according to their characteristic network structure. As the NPM is derived from the high-tech environment via a systematic literature analysis a comparison of the actual innovation performance according to the IPM and the results of the NPM allows a conclusion regarding efficient network arrangements corresponding to those in the high-tech industry (see 5. Conclusion).

The NPM uses a similar approach as the IPM, aggregating weighted factors. In this case, the parameter values of five specific network factors are evaluated for both projects. The network factor *degree of locality* is to be discussed as an example of the procedure.

Degree of locality refers to the local distribution of the network partners. The analysis of the relevant publications has identified a positive effect of a close-knit network with relatively small distances between the partners due to e.g. the easier transfer of implicit information or a reduction of communication costs. Consequently the literature analysis results in a strongly positive correlation of *0.82* between a higher *degree of locality* and innovative performance. (Powell & Grodal 2005, p. 66). The parameter values of the network factor were assessed via the measurement of the average distance of the projects locations to the (if existing) closest branch of their respective collaboration partners. Project A's average distance sums up to

157km while Project B has to travel *119km* only. The corresponding normalised values can be observed in the following table 4 just like those of the remaining network factors that also have been adequately determined. Furthermore, the findings are presented in a spider graph (figure 3) giving an overview of the characteristic network structures of Project A and Project B.

Figure 3: Results of Network Performance Model (NPM)



The resulting figure "Network Performance" yields values of 100% for Project A and 94,8% for Project B (Table 4). While the factors *Centrality* and *Degree of Locality* weakly contribute to the performance of Project A's network, the *number of network partners*, the uncommon *degree of heterogeneity* of partners as well as the *tie strength* of the closely-knit network overcompensates these effects and cause a better Network Performance than that of Project B's consortium.

Table 4: Results of Network Performance Model (NPM)

		Project A	***Project B***
Network factor	***Wgt***	$(NF_i(A))_{norm}$	$(NF_i(B))_{norm}$
Number of network partners	0.56	1	0.38
Centrality	0.75	0.38	1
Degree of locality	0.82	0.76	1
Degree of heterogeneity	0.69	1	0.73
Tie strength	0.61	1	0.5
Network Performance		**2.69**	**2.55**
$(\text{Network Performance})_{norm}$		**100%**	**94,8%**

5. Conclusion

So far, development networks in the electric mobility sector have rarely been covered in both theoretical and empirical research. The particular importance of networks in situations of scattered and uncertain knowledge and the lack of corresponding research encourage us to systematically capture the innovation effect of networks in this field of strong public interest. Studies in this area encounter many problems of qualitative methods. Measurements of innovation have limited validity as "multifaceted nature of innovation makes a concise measure of innovation, which is appropriate to all firms, impossible" (Rogers 1998, p. 21). In this paper, the use of systematic expert interviews has been a suitable mean to align existing measurements to the peculiarities of electric vehicle development resulting in the Innovation Performance Model (IPM). The networking dimension of innovation has been covered by the Network Performance Model (NPM) integrating numerous of network effects, that allows to comprehensively measure the impact of network design on the network's innovation performance.

Within given assumptions we find that the characteristics of Project A's network provide more innovation-momentum than the Project B's network applying the Network Performance Model (NPM). Additionally, we find that these results – although the underlying measurements have been derived from findings in the high-tech industry – are comparable to the actual innovation performance of the developments captured by the Innovation Performance Model (IPM). These results contribute to support our hypotheses that the ideas about an "innovation-friendly network" are transferable to the disruptive setting of electric vehicle development as it resembles the high-tech setting (see theory section). Being consistent with the general argument, that network structure matters, the analysis supports the idea to pay particular attention to ensuring a dedicated network design for managerial practice.

Although, as pointed out in the methods section, data has been aggregated for indicators of assumed correlations, the problems of building indicators remain a weakness of such studies. While our models use weightings to account for individual effects, more robust methods like the principal components analysis should be taken into consideration to prevent redundancy in case of highly correlated factors. A few figures of the case studies' datasets were derived from limited public information or reasonable assumptions. Further research on this issue requires an even deeper insight in the exact structure and activities of the individual development consortium. In addition, future research activities are stimulated to consider more case studies to statistically define the explanatory capacity of this approach controlling other effects and including robustness checks. As innovation owns a multi-faceted and much case-dependent nature, the shortcomings of this qualitative research will scarcely be overcome. Research will thus continuous to rely heavily on case studies and imperfect indicators of underlying phenomena.

Summarizing the results of this paper and bearing in mind the importance of the new technology for the industry, our study's performance models have considerable promise for broader application to the analysis of current development networks, and may provide a stronger empirical underpinning for the qualitative research in this field.

References

Adams, R.; Bessant, J. and Phelps, R. (2006): Innovation management measurement. A review. In *International Journal of Management Reviews* 8 (1), pp. 21–47.

Becheikh, N.; Landry, R. and Amara, N. (2006): Lessons from innovation empirical studies in the manufacturing sector. A systematic review of the literature from 1993-2003. In *Technovation* 26 (5-6), pp. 644–664.

Borgatti, S.P. and Li, X. (2009): On Social Network Analysis In A Supply Chain Context. In *Journal of Supply Chain Management* 45 (2), pp. 5–22.

Borgatti, S.P.; Mehra, A.; Brass, D.J. and Labianca, G. (2009): Network Analysis in the Social Sciences. In *Science Policy Support Group* 323 (5916), pp. 892–895.

Brand, M. and Herrmann, F. (2012): Elektromobile Wertschöpfungskette. Strategische Allianzen und Internationale Zusammenarbeit. In *ZWF* 107 (10), pp. 717–721.

Chandler, A.D. (1962): Strategy and structure: chapters in the history of the industrial enterprise. Cambridge: M.I.T. Press.

Christensen, C.M. (1997): The innovator's dilemma. When new technologies cause great firms to fail. Boston, Mass: Harvard Business School Press (The management of innovation and change series).

Davis, J.P. and Eisenhardt, K.M. (2011): Rotating Leadership and Collaborative Innovation. Recombination Processes in Symbiotic Relationships. In *Administrative Science Quarterly* 56, pp. 159–201.

Fioretti, G. (2012): Agent-Based Simulation Models in Organization Science. In *Organizational Research Methods* 16 (2), pp. 227–242.

Flor, M.L. and Oltra, M.J. (2004): Identification of innovating firms through technological innovation indicators. an application to the Spanish ceramic tile industry. In *Research Policy* 33 (2), pp. 323–336.

Garcia Sanz, F.J.; Semmler, K.; Walther, J. (2007): Die Automobilindustrie auf dem Weg zur globalen Netzwerkkompetenz. Effiziente und flexible Supply Chains erfolgreich gestalten. Berlin: Springer.

Glass, G.V. (1976): Primary Secondary and Meta-Analysis of Research. In *Educational Researcher* 10 (5), pp. 3–8.

Google (2013): Google Ngram Viewer. Available at URL: http://books.google.com/ngrams Accessed August 8, 2013.

Grupp, Hariolf (1997): Messung und Erklärung des technischen Wandels. Grundzüge einer empirischen Innovationsökonomik. Berlin: Springer.

Hagedoorn, J. (2002): Inter-firm R&D partnerships. An overview of major trends and patterns since 1960. In *Research Policy* 31 (4), pp. 477–492.

Hagedoorn, J. and Cloodt, M. (2003): Measuring innovative performance. Is there an advantage in using multiple indicators? In *Research Policy* 32 (8), pp. 1365–1379.

Jaffe, Adam B.; Trajtenberg, Manuel (2002): Patents, citations, and innovations. A window on the knowledge economy. Cambridge, Mass.: MIT Press.

Kampker, A.; Burggräf P.; Deutskens C. and Niebuhr C. (2013a): Competitive Strategies for Value Creation During Disruptive Innovations. In D. Dimitrov, C. Schutte (eds.): Proceedings International Conference on Competitive Manufacturing COMA´13. International Conference on Competitive Manufacturing. Stellenbosch, South Africa, 30.1. Stellenbosch University, pp. 469–477.

Kampker, Achim; Deutskens, Christoph; Heimes, Heiner; Nee, Carsten; Sommer, Christopher; Wowreczko, Danuta (2013b): Herausforderungen disruptiver Innovationen am Beispiel der Elektromobilität. Aachen: Apprimus.

Kampker, A.; Burggraf, P.; Deutskens, C.; Heimes, H. and Schmidt, M. (2012): Process alternatives in the battery production. In Electrical Systems for Aircraft, Railway and Ship Propulsion (ESARS), 2012. Bologna, 16-18 Oct. 2012. Piscataway, N.J: IEEE.
Kampker, A. and Deutskens, C. (2010): Über das Netzwerk zum Serienprodukt. In *VDMA-Nachrichten* 89 (2), pp. 14–15.
Kampker, A.; Franzkoch, B. and Nowacki, C. (2011): Networked product and production development for lithium-ion batteries. In H.A. ElMaraghy (ed.): Enabling Manufacturing Competitiveness and Economic Sustainability. Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (Carv2011), Montreal, Canada, 2-5 October 2011. New York: Springer, pp. 215–220.
Kasperk, G.; Drauz, R. and von Mangoldt, J. (2012): Kooperationsstrategien von Automobilproduzenten entlang der sich neu ordnenden Wertschöpfungskette. In H. Proff et al. (eds.): Zukünftige Entwicklungen in der Mobilität. Betriebswirtschaftliche und technische Aspekte. Wiesbaden: Gabler Verlag, pp. 391–404.
Kleinknecht, A.; van Montfort, K. and Brouwer, E. (2002): The non-trivial Choice between Innovation Indicators. In *Economic Innovation New Technologies* 11 (2), pp. 109–121.
Mowery, D.C. (1988): International collaborative ventures in U.S. manufacturing. Cambridge: Cambridge University Press.
Müller, P.; Kasperk, G. and Kampker, A. (2013): Radikale Innovation durch effiziente Netzwerke. In H. Proff (ed.): Radikale Innovationen in der Mobilität. Technische und betriebswirtschaftliche Aspekte (5). Wissenschaftsforum Mobilität. Duisburg, June 18, 2013. Universität Duisburg-Essen: Springer Gabler.
Phelps, C.; Heidl, R. and Wadhwa, A. (2012): Knowledge, Networks, and Knowledge Networks: A Review and Research Agenda. In *Journal of Management Studies* 38 (4), pp. 1114–1166.
Piller, F.T.; Waringer, D. (1999): Modularisierung in der Automobilindustrie. Neue Formen und Prinzipien. Aachen: Shaker.
Powell, W.W. and Grodal, S. (2005): Networks of Innovators. In J. Fagerberg, D.C. Mowery, R.R. Nelson (eds.): The Oxford handbook of innovation. Oxford, New York: Oxford University Press, pp. 56–84.
Powell, W.W.; Koput, K.W. and Smith-Doerr, L. (1996): Interorganizational Collaboration and the Locus of Innovation. Networks of Learning in Biotechnology. In *Administrative Science Quarterly* 41 (1), pp. 116–145.
Powell, W.W.; Koput, K.W.; Smith-Doerr, L. and Owen-Smith, J. (1999): Network Position and Firm Performance. Organizational Returns to Collaboration in the Biotechnology Industry. In *Research in the Sociology of Organizations*, special volume, pp. 1–52.
Powell, W.W.; Packalen, K. and Whittington, K. (2012): Organizational and Institutional Genesis. The Emergence of High-Tech Clusters in the Life Sciences. In J.F. Padgett, W.W. Powell (eds.): The emergence of organizations and markets. Princeton: Princeton University Press, pp. 434–465.
Propfe, B.; Kreyenberg, D.; Wind, J. and Schmid, S. (2013): Market penetration analysis of electric vehicles in the German passenger car market towards 2030. In *International Journal of Hydrogen Energy* 38 (13), pp. 5201–5208.
Rogers, Mark (1998): The definition and measurement of innovation. Parkville, Vic: Melbourne Institute of Applied Economic and Social Research (Working paper / Melbourne Institute of Applied Economic and Social Research, 10/98).
Rosenberg, N. (1994): Exploring the Black Box. Cambridge: Cambridge University Press.

Schuh, G.; Wellensiek, M. and Nollau, S. (2010): Erfolgreiche Technologieentwicklung im Unternehmensnetzwerk. Herausforderungen in der Auftragsentwicklung von Technologien durch virtuelle Technologieentwicklung bewältigen. In *ZWF* 105 (3), pp. 189–193.

Smith, K. (2005): Measuring Innovation. In J. Fagerberg, D.C. Mowery, R.R. Nelson (eds.): The Oxford handbook of innovation. Oxford ;, New York: Oxford University Press, pp. 148–178.

Stegbauer, C. (2010): Netzwerkanalyse und Netzwerktheorie. Ein neues Paradigma in den Sozialwissenschaften. In *Netzwerkanalyse und Netzwerktheorie* 1.

Thomes, P. (2013): Elektromobilität. eine historisch basierte Analyse. In A. Kampker, D. Vallée, A. Schnettler (eds.): Elektromobilität. Grundlagen einer Zukunftstechnologie. Berlin, Heidelberg: Springer, pp. 6–15.

Wessel, M. and Christensen, C.M. (2013): So überleben Sie disruptive Innovationen. In *Harvard Business Manager* (Februar), pp. 20–31.

Whittington, K.B.; Owen-Smith, J. and Powell, W.W. (2009): Networks, Propinquity, and Innovation in Knowledge-intensive Industries. In *Administrative Science Quarterly* 54 (1), pp. 90–122.

Yin, Robert K. (2009): Case study research. Design and methods. 4th ed. Los Angeles, Calif: Sage Publications (Applied social research methods series, 5).

A Proactive Design of Robust Supply Chain Structure by Portfolio Model

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Abstract: This research, focusing on supply chain of car industry, proposes a design methodology of compromised expected procure/supply quantity with its acceptable fluctuation for concerned firms. The proposed design model can be called supply chain portfolio design problem under competitive business environment. Example application, *i. e.* a case of supply chain among plural car assemblers and tire suppliers, is also given for demonstrating its rationality.

Keywords: Supply Chain Portfolio, Robust Operation, Risk Aversive Design, Global Business Environment, Negotiation, Industrial Parts, Car Assembler, Tire Supplier.

1. Introduction

In the past three decades, industrial globalisation has been advanced all over the world in terms of slow progress in the entry to fast in the last 10 years. Corresponding to this trend, structure of industrial supply chain has been changed to meet rising business requirements such as competitive global procurement, environmental sustainability, minimisation of business risk etc. and now its refinement on the global platform is the matter of argument.

Especially, supply chain in the global context has various serious problems due to ultimate competition among global players and also natural as well as economic disasters. There are three typical approaches to cope with these phenomena, *i. e.* design of supply chain effectiveness/ durability, risk aversive structure and operations for resilience. The first issue, effectiveness/ durability design, is the well-recognised key importance in the normal as well as turbulent operational environment. The second, design of risk aversive structure (Hibiki, 2001; Luenberger *et al*, 2002), is recently highlighted as an important subject to survive in destructive phenomena. Also, the third, design of resilient operations, is a compulsory to realise possible quick recovery (Katayama *et al*, 2011).

Former two issues are regarded as proactive approaches and the last is categorised in a reactive scheme. In reality, business firms have to move toward these three matters simultaneously, however, the author focuses on the second topic in this paper.

Looking at Japanese car industry, domestic supply chain system called KEIRETSU, which is based on exacting one to one corresponding relation between specific suppliers and assemblers, has been gradually weakened and the relation among concerned manufacturers tends to shift to nested or network structure. Also recently, this trend is accelerated to avoid impacts of disastrous phenomena such as catastrophic earthquakes, large scale floods, countries' economic disasters, political collisions among nations. These tragedies cause malfunction of local industrial activities and, as operations spatially diverge with mutual linkage in terms of supply/delivery network, effects rapidly transfer throughout this globe. One key problem in this situation is how to design network structured supply chain with minimum collision among firms on the chain, where each firm has its own procurement/supply policy and intend to realise its objective.

2. One to Many and/or Many to One Supply Chain Portfolio Model for Industrial Parts Procurement (Katayama, 2012)

In this chapter, the cases of one to many and/or many to one supply/procurement chains are focussed to discuss. Here, the former means one downstream firm and plural upstream suppliers are considered as the member of supply chain, which are operating under pull scheme (See the left of Figure 1) and the latter means plural downstream firms and one upstream supplier are considered as the member of supply chain, which are operating under push scheme (See the right of Figure 1).

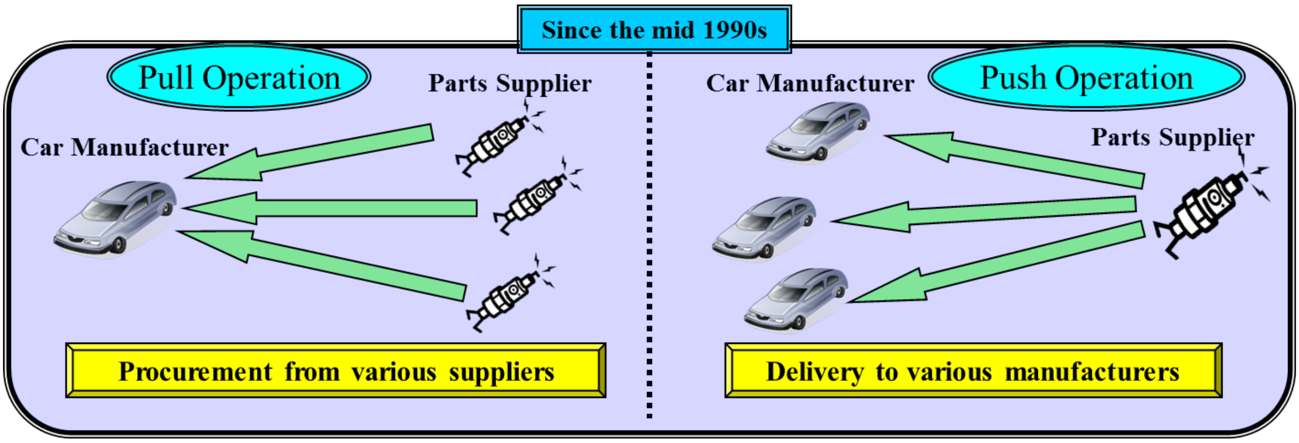


Figure 1. Structure of Car Parts Supply Chain (Isahaya *et al*, 2009; Isahaya *et al*, 2010)

Pull operation is conducted by procurement-side, *i. e.* assembler-side decision model. In this case, problem is to determine how many parts must be procured from which suppliers (Uchiyamada, 2008). These are represented by procurement rates (weighting factors) from each supplier. On the other hand, push operation is activated by delivery-side. So, there could be supplier-side decision model, which is to determine how many parts can be delivered to which assemblers. These are represented by delivery rates (weighting factors) to each assembler. The way of determining these rates is proposed through procurement/delivery portfolio consideration.

2.1. Contract Establishment Model for Stable Procurement with Designed Risk

In this section, contract establishment model among assemblers and suppliers is discussed. For realising risk aversive stable manufacturing, car assemblers, prior to the occurrences of disastrous situation, can consider to establish portfolio-like contracts with various suppliers, which are making the same parts. Suppliers, the counterparts, can also devote to examine making contracts with various assemblers for pursuing stable trade with low risk such as stoppage of purchase from assemblers.

A multi-objective stochastic optimization problem, with which both car manufacturers and parts suppliers cope, was formulated (Isahaya *et al.*, 2011) in terms of pull model and push model respectively. Essence of these models is described as follows.

(1) Mathematical Formulation

<Pull Model>

Objective Function 1:

Maximization of the average volume of tires procured from tire factories

$$\text{Max} \quad J_1 = \frac{1}{T}\sum_{t \in T} B_t \tag{1}$$

Objective Function 2:

Minimization of the variance of expected number of tires procured from tire factories

$$\text{Min} \quad J_2 = {\sigma_b}^2 \tag{2}$$

Constraints:

$$B_t = \sum_{i=1}^{n} b_{i,t} \tag{3}$$

$$b_{t,t} = v_i \hat{S}_{i,t} \tag{4}$$

$$0 \le v_i \le v_{\max} \tag{5}$$

$${\sigma_b}^2 = \frac{\sum_{t \in T}\left(B_t - \frac{1}{T}\sum_{t \in T} B_t\right)^2}{T} \tag{6}$$

<Notation>

T :Number of periods in time horizon

Bt :Total planned number of tires procured by the specific car factory from tire factory i (i=1,…,n) in period t

bi,t :Planned number of tires procured by the specific car factory from tire factory i in period t

$\hat{S}_{i,t}$:Expected number of tires produced by tire factory i in period t

Vi :Delivery ratio of tire factory i (Portfolio control parameters)

$Vmax$:Maximum supply ratio of tire factory i

${\sigma_b}^2$:Variance of expected number of tires procured in each period throughout considered time horizon

<Push Model>

Objective Function 1:

Maximization of the average volume of tires delivered to car factories

$$\text{Max} \qquad J_3 = \frac{1}{T}\sum_{t \in T} Q_t \tag{7}$$

Objective Function 2:

Minimization of the variance of tires delivered to car factories

$$\text{Min} \qquad J_4 = \sigma_q{}^2 \tag{8}$$

Constraints:

$$Q_t = \sum_{j=1}^{n} q_{j,t} \tag{9}$$

$$q_{j,t} = u_j \hat{D}_{j,t} \tag{10}$$

$$0 \le u_j \le u_{\max} \tag{11}$$

$$\sigma_q{}^2 = \frac{\sum_{t \in T}\left(Q_t - \frac{1}{T}\sum_{t \in T} Q_t\right)^2}{T} \tag{12}$$

<Notation>

- T :Number of periods in time horizon
- Q_t :Total planned number of tires delivered from specific tire factory to car factory j (j=1,…,n) in period t
- $q_{j,t}$:Planned number of tires delivered from the specific tire factory to car factory j in period t
- $\hat{D}_{j,t}$:Expected number of tires delivered to car factory j in period t
- Uj :Delivery ratio of car factory j (Portfolio control parameters)
- U_{max} :Maximum delivery ratio of car factory j
- $\sigma_q{}^2$:Standard deviation of expected number of tires delivered in each period throughout considered time horizon

(2) Example Result (Pull Model Case)

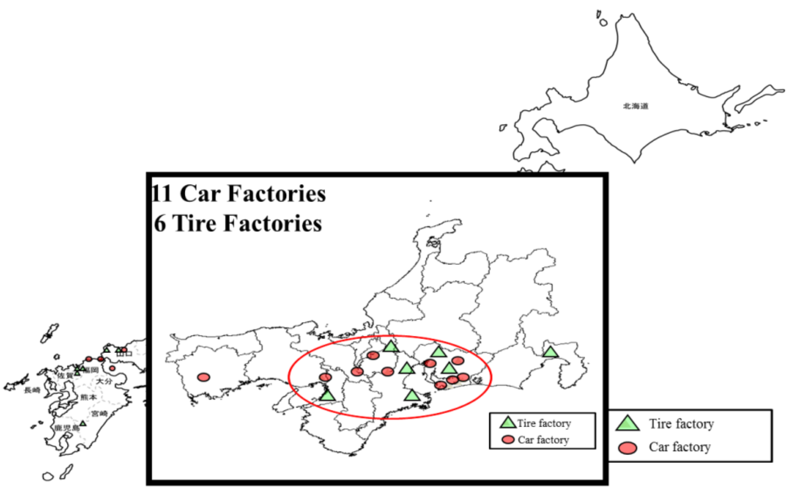


Figure 2. Area in Consideration

A result of pull model case, *i.e.* procurement network design, is introduced in this section. Focused area for this problem is mid-area of mainland Japan called Kwansai-Chubu area as shown in Figure 2. Here, car assembly factories (11 sites) and tire manufacturing factories (6 sites) are considered as down-stream and up-stream manufacturers.

Portfolio characteristics of this problem under the supposed business situation, *i. e.* average procurement level and standard deviation of number of tires, is obtained by modifying weighting factors mentioned earlier. Rational trade plan, *i. e.* Pareto optimal solution of portfolio problem, is derived by a smart numerical calculation method (Katayama *et al*, 1988; Fonseca *et al*, 1993) as shown in Figure 3.

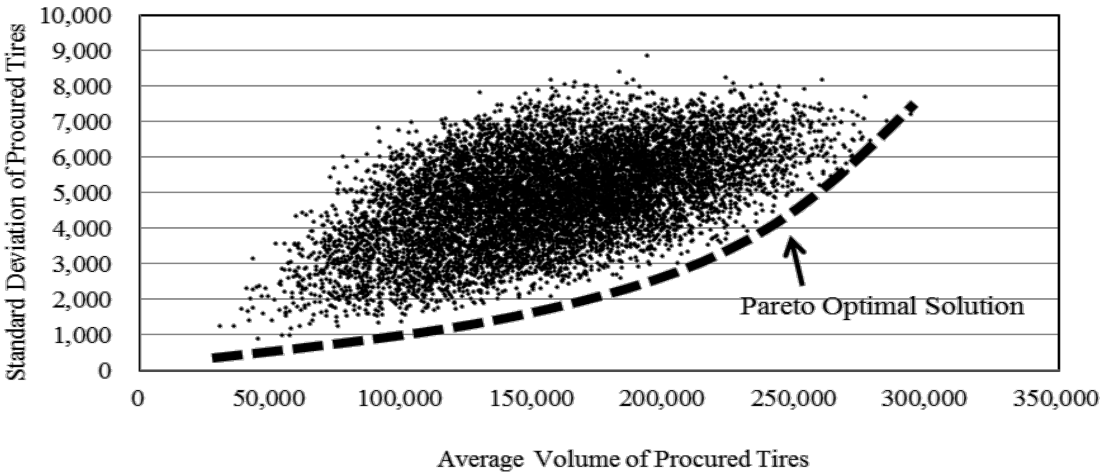
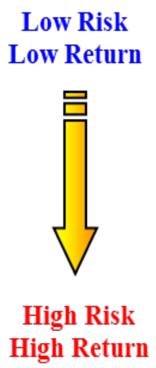


Figure 3. Characteristics of Portfolio Selection and Pareto Optimal Solution

Table 1. Procurement Rates for Pareto Optimal Solution



Standard Deviation		Average Volume	Tires Procured from (Tire Company, Factory)					
Range	Measured Value		(B,H)	(Y,M)	(Y,S)	(S,N)	(S,I)	(T,K)
500-1000	2173.5	59732	0.117	0.472	0.053	0.197	0.133	0.035
1001-1500	5142.7	113586	0.233	0.618	0.043	0.209	0.359	0.447
1501-2000	6861.6	152642	0.307	0.800	0.166	0.203	0.501	0.609
2001-2500	7735.0	189670	0.358	0.989	0.197	0.477	0.681	0.602
2501-3000	10171.4	222026	0.459	0.998	0.183	0.495	0.847	0.731
3001-3500	10418.6	240345	0.472	0.975	0.269	0.899	0.512	0.697
3501-4000	11753.5	266490	0.509	0.990	0.455	0.744	0.632	0.995
4001-4500	13272.3	290674	0.587	0.964	0.527	0.885	0.972	0.752
4501-5000	16450.1	322186	0.722	0.961	0.514	0.842	0.671	0.994
5001-5500	17731.1	340182	0.778	0.947	0.528	0.870	0.955	0.944
5501-6000	17163.3	347398	0.737	0.877	0.804	0.980	0.907	0.944
6001-6500	19216.2	368324	0.840	0.953	0.794	0.929	0.869	0.921
6501-7000	21758.3	398775	0.957	0.988	0.835	0.976	0.802	0.918
7001-7500	22660.4	406790	0.989	0.981	0.939	0.812	0.892	0.963

2.2. Sensitivity Analysis on Portfolio Performance

In this section, the affects of change of business variables/parameters on Pareto optimal solution derived in the previous section is examined by sensitivity analysis.

(1) Procedure

General procedure of sensitivity analysis is that, Step 1a: Perturbing the values of system variables and/or parameters that affects system performance and then Step 2a: Evaluating system performance. Reverse analysis is also often required, namely, Step 1b: Setting desirable system performance then Step 2b: Identifying the variables and/or parameters and their values that realise desirable performance.

Here, consider the case of manufacturing malfunction of a tire factory as change of business variables, *i. e.* production volume, and examine its affect on Pareto optimal solution, to which the former type analysis is suitable (Ishikawa *et al.*, 2012a-b). The way to extract trade-off relation between average (return) and standard deviation (risk) is the same as described in section 2.1.

(2) Example Result (Pull Model Case)

Figure 4 illustrates Pareto optimal solution (before) and perturbed trade-off relation (after). It is immediately noticed that supplier malfunction brings huge negative affect on procurement performance.

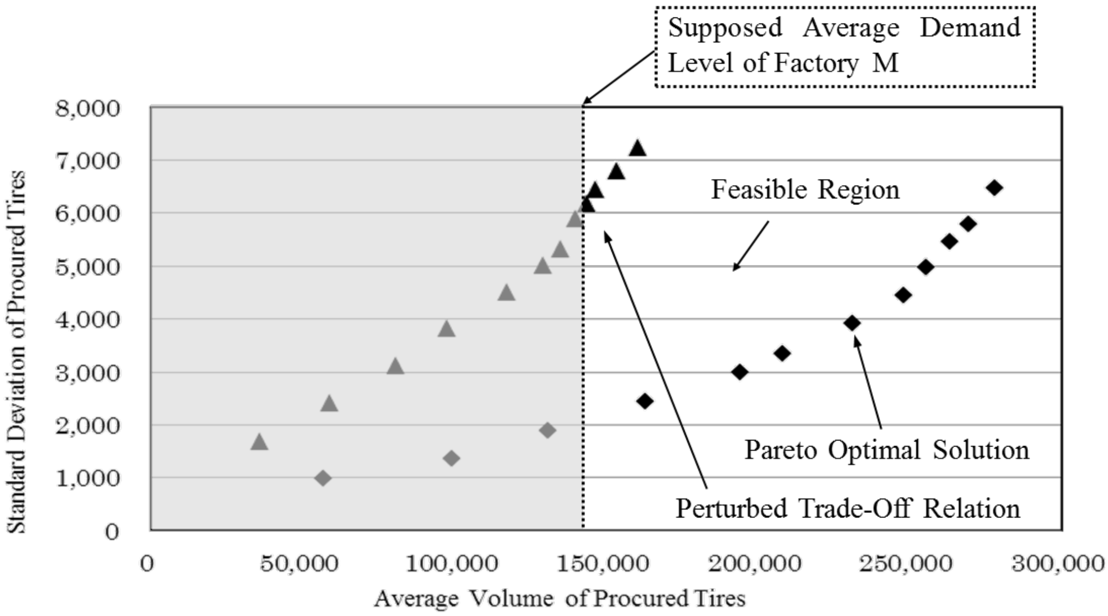


Figure 4. Affect on Procurement Performance caused by malfunction of a supplier factory

3. Many to Many Supply Chain Portfolio Model for Industrial Parts Procurement (Ishikawa and Katayama, 2013)

In this chapter, as an extension of Chapter 2, a case of two to two supply/procurement chain is focussed to discuss, which is an simple example of many to many supply chain portfolio model. This model consists of following six steps.

Step 1: Evaluation of standard deviation and trading performance data of each factory

Step 2: Generation of expected value of the desired trading volume by portfolio parameter v

Determining a portfolio parameter v by random number generation, then, expected value of the desired trading volume and standard deviation of each factory are calculated.

Step 3: Identifying differences of desired trading volumes among considered factories

Step 4: Decision making the trading volumes among factories

Determining the trading volume of tires in each factory to minimize the distance of desired trading volume derived in Step3.

Step 5: Deriving the Pareto optimal characteristics of each factory

Through regeneration of the portfolio parameters *v* and repetition of Step2-Step4 over 1000 times, a portfolio graph and Pareto optimal curve is obtained by an effective logical procedure (Katayama *et al.*,1988; Fonseca *et al.*, 1993).

Step 6: Derivation of the minimum overall distance among trading points on each Pareto optimal curve

Deriving an approximate curve of the Pareto optimal solution, and then, calculating the distances between trading point and the Pareto optimal curve. In this study, the trading point, which has the minimum total distance between the Pareto solution of each factory, is identified as the overall optimal trading volume.

3.1 Collect Data

Table 2 and Table 3 show average and standard deviation of the production volumes of each factory.

Table 2. Average and Standard Deviation of the Production Volumes of Tire Factories [Unit: Tires]

	Average Volume	Standard Deviation
Tire factory a	150,609	6,066
Tire factory b	242,159	20,981

Table 3. Average and Standard Deviation of the Production Volumes of Car Factories [Unit: Tires]

	Average Volume	Standard Deviation
Car factory A	160,076	7,768
Car factory B	231,612	19,883

3.2 Generation of the Portfolio Parameters

Generation of portfolio parameter *v* is performed by random number generation. Table 4 and Table 5 show the range of random numbers. The meaning of the value of the portfolio parameter 1 – 3, for instance, is that factories want to trade more than the current total trading volumes such as not smaller than now and up to triple. In this study, it is assumed that the trading volume lies between zero to triple of the current volume, so the values of the possible portfolio parameters are set from 0 to 3 to consider the reduction and expansion of trading volume in the future.

The expected value of the desired trading volume and standard deviation of each factory is determined by multiplying the average and standard deviation of current trading volume measured in Step 1 and the portfolio parameters. Formula is in (13) and (14).

Table 4. Tire Factory's Trade Coefficient (PUSH Model)

Procurement Site	Trade Coefficient with Car Factory A : v_A	Trade Coefficient with Car Factory B : v_B
Tire factory a	$1 \leqq v_{aA} \leqq 3$	$0 \leqq v_{aB} \leqq 2$
Tire factory b	$1 \leqq v_{bA} \leqq 3$	$0 \leqq v_{bB} \leqq 2$

Table 5. Car Factory's Trade Coefficient (PULL Model)

Delivery Site	Trade Coefficient with Tire Factory a : v_a	Trade Coefficient with Tire Factory b : v_b
Car factory A	$1 \leqq v_{Aa} \leqq 3$	$0 \leqq v_{Ab} \leqq 2$
Car factory B	$1 \leqq v_{Ba} \leqq 3$	$0 \leqq v_{Bb} \leqq 2$

・Expected Value of the Desired trading Volume and Standard Deviation

$$E[Q_i] = \sum (v_{it} \times E[T_t]) \qquad (13)$$

$$E[V_i] = \sum (v_{it} \times E[S_t]) \qquad (14)$$

<Notation>

$E[Q_i]$	: Expected Value of the Desired trading Volume in Factory i ($i = a, b, A, B$)
$E[V_i]$	: Standard Deviation on Expected Value of the Desired trading Volume in Factory i ($i = a, b, A, B$)
$E[T_t]$	: Average Trading Performance in Factory i ($i = a, b, A, B$)
$E[S_t]$	: Past Standard Deviation in Factory i ($i = a, b, A, B$)
v_{it}	: Portfolio Parameter in Factory i with Factory t ($i, t = a, b, A, B$)

For example, expected value of the desired trading volume of tire factory a is calculated by "Expected value of the desired trading volume with car factory A + Expected value of the desired trading volume with car factory B", namely, "v_{aA} × trading performance of car factory A + v_{aB} ×trading performance of car factory B". In the same way, standard deviation is derived by "v_{aA} × standard deviation of car factory A＋v_{aB} × standard deviation of car factory B".
This means tire factory a wants to trade v_{aA} × current trading volume with car factory A and v_{aB}

×current trading volume with car factory B.
These calculations are performed also for tire factory b, car factory A and B.

3.3 Identification of the Difference between Factories Desired Trading Volume and Decision between Factories Trading Volume

Here, let us consider the trade of tire factory a and car factory A. Blue star and red star, in Figure 5, shows expected value of the desired trading volume and standard deviation of tire factory a and car factory A respectively. Then, the distance of the expected value of the desired trading volume is regarded as J_{EaA} and standard deviation is J_{VaA}. It might be able to determine the optimal trading volume of each factory by minimizing the value of J_E. For J_V, as the desired value set of variations is difficult, only J_E is considered here (See Figure 6). The optimal trading volume is derived in the same way in respect to other transactions.

This study considers three cases of the relationship among factories.

・Case 1: Tire factory : Car factory = 0 : 1

It is the case that the power of the car factory is strong and the desired trading volume of the car factory is the trading volume as it is.

The trading volume = 0 * the desired trading volume of the tire factory + 1 * the desired trading volume of the car factory

・Case 2: Tire factory : Car factory = 0.5 : 0.5

It is the case that the power of each factory is even and the trading volume is he middle of the desired trading volume of both facyoties.

The trading volume = 0.5 * the desired trading volume of the tire factory + 0.5 * the desired trading volume of the car factory

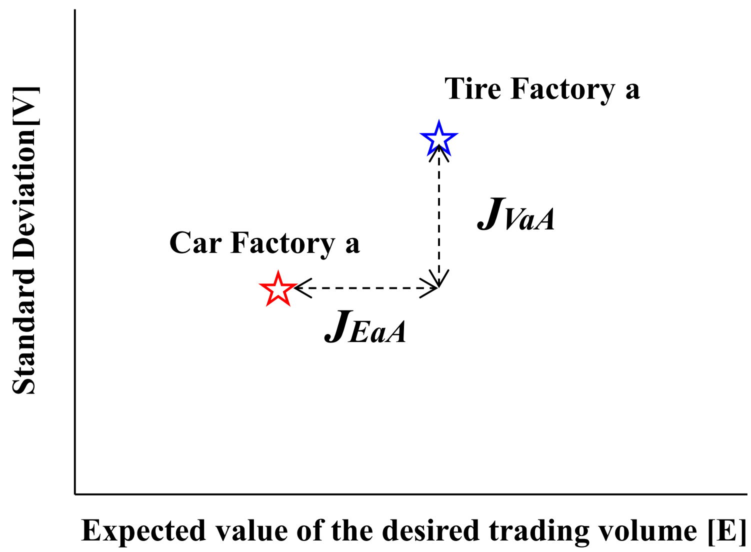


Figure 5. Expected Value of the Desired trading Volume and Standard Deviation on Tire Factory a and Car Factory A

·Case 3: Tire factory : Car factory = 1 : 0

It is the case that the power of the tire factory is strong and the desired trading volume of the tire factory is the trading volume as it is.

The trading volume = 1 * the desired trading volume of the tire factory + 0 * the desired trading volume of the car factory

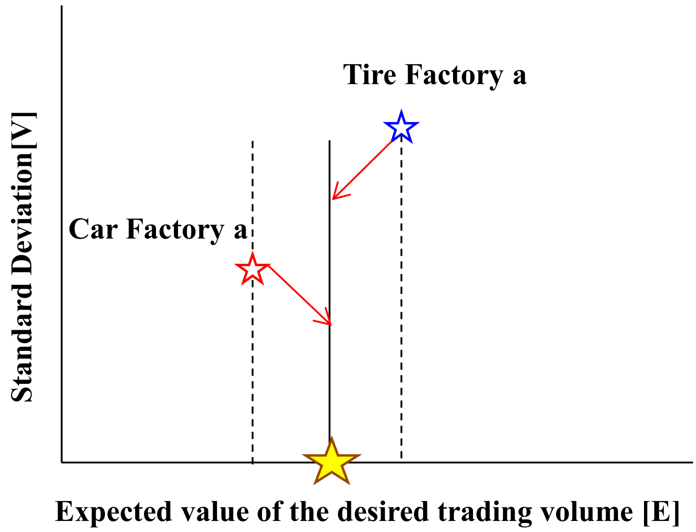


Figure 6. Decision Model the Desired Trading Volume on Tire Factory a and Car Factory A (Determined by Portfolio Graph)

3.4. Results

Through regeneration of the portfolio parameters *v* and repetition of Step2-Step4 over 1000 times, Figure 7-9 are obtained, for example, as the results.

Blue star and red star in figure respectively shows trading point of the current situation and trading point to be total optimization.

·Case 1: Tire factory : Car factory = 0 : 1

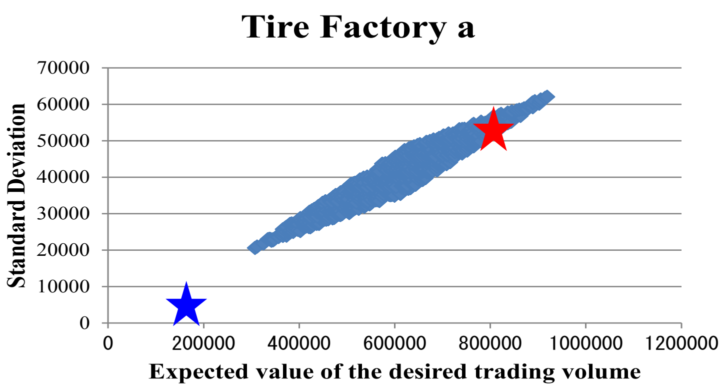


Figure 7. Portfolio Graph in Tire factory a (0 : 1)

・Case 2: Tire factory : Car factory = 5 : 5

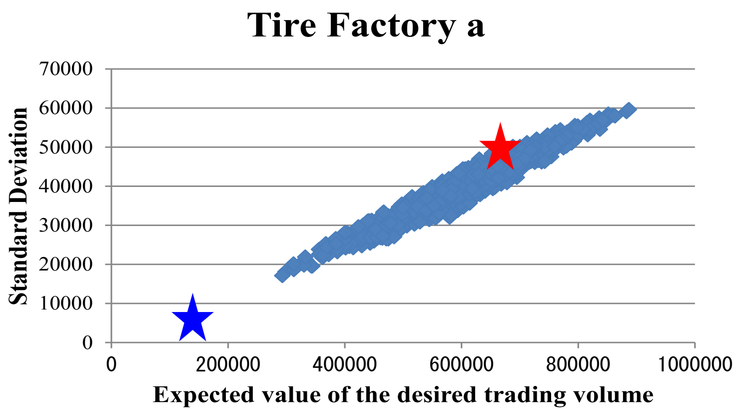


Figure 8. Portfolio Graph in Tire factory a (0.5 : 0.5)

・Case 3: Tire factory : Car factory = 1 : 0

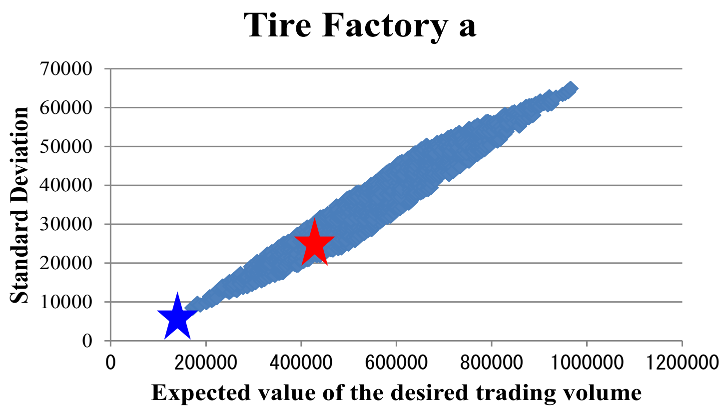


Figure 9. Portfolio Graph in Tire factory a (1 : 0)

In reference to Katayama *et al*. and Fonseca *et al*., the approximate curve of the Pareto solution is derived. Figure 10 is an example in case of the tire factory a. When the Pareto curve is derived, a quadratic function is used for approximation to make easy calculation.

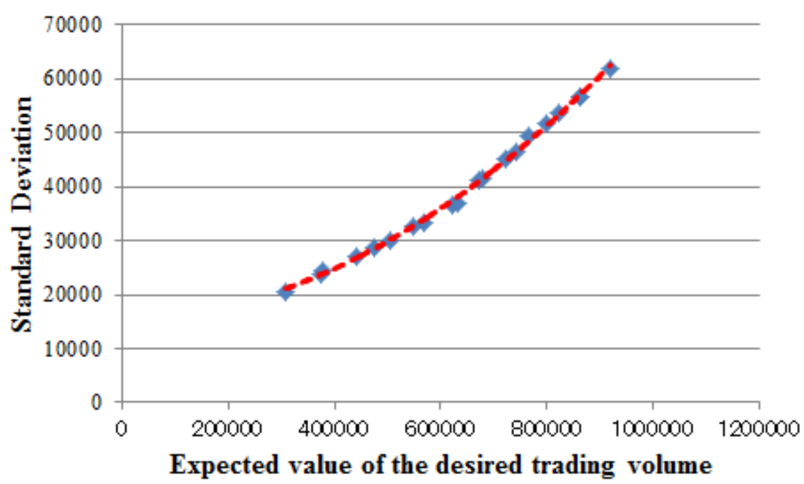


Figure 10. Pareto Optimal Curve

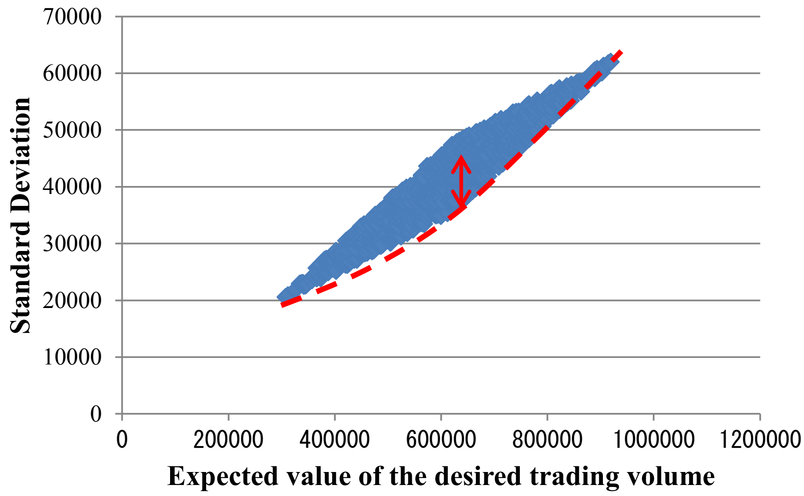


Figure 11. The Distance to the Pareto Optimal Curve from Trade Point

The distance between approximate curve and each trade point in each factory is the next matter. The definition of “distance” is, as shown by the arrow and red in Figure 11, the difference of the standard deviation of the approximate curve and trade point. In this study, trade point, where total distance of each factory is minimum, is the overall optimal solution. The calculation of the total distance of each case is as follows.

・Case 1: Tire factory : Car factory = 0 : 1

The total distance = 0 * (The distance of tire factory a + The distance of tire factory b) + 1 * (The distance of car factory A + The distance of car factory B)

・Case 2: Tire factory : Car factory = 0.5 : 0.5

The total distance = 0.5 * (The distance of tire factory a + The distance of tire factory b) + 0.5 * (The distance of car factory A + The distance of car factory B)

・Case 3: Tire factory : Car factory = 10 :

The total distance = 1 * (The distance of tire factory a + The distance of tire factory b) + 0 * (The distance of car factory A + The distance of car factory B)

Table 6 and Table 7 show total and each factory’s distance, trade average volume and standard deviation in each case.

From the obtained results, it is recognized that the distances of tire factories of case 1 and car factories of case 3 are disastrous, especially, factory a’s difference in distance is terrible in all the cases. Also it seems necessary to expand the production scale of tire factory a and car factory A. This mean that current situation is far from optimal solution in any case. However, as there isn’t a large difference in optimal trading volume in any case of the car factory B, adjustment of the production volume is likely to be not necessary.

Table 6. The Total Distance of Each Case in Optimal Solution

	Tire factory a	Tire factory b	Car factory A	Car factory B	Total
Case 1	2646.719828	1146.929749	68.28352319	101.5637727	169.8472959
Case 2	3657.407159	152.5268988	90.57217813	575.2075923	2237.856914
Case 3	221.3732888	1.143674186	5901.358459	832.7646632	222.516963

Table 7. Average and Standard Deviation of the Production
of Car Factories in Optimal solution [Unit: Tires]

	Tire factory a		Tire factory b		Car factory A		Car factory B	
	Average Volume	Standard Deviation	Average Volume	Standard Deviation	Average Volume	Standard Deviation	Average Volume	Standard Deviation
Case 1	824378.2	54290.3	89598.8	5974.6	487587.5	21759.7	426389.4	19184.2
Case 2	706450.5	45201.3	163807.4	9652.2	532023.5	26895.8	338234.4	15731.1
Case 3	420184.8	22032.5	297741.3	14448.4	673919.9	40937.8	44006.2	1771.2

4. Concluding Remarks

This paper, focusing on supply chain of car industry, proposed a design methodology of compromised expected procure/supply quantity with its acceptable fluctuation for concerned firms. This model can be called a supply chain portfolio design problem under competitive business environment. Example application, *i. e.* a case of supply chain among plural car assemblers and tire suppliers, was also given for demonstrating its rationality.

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References

Fonseca, C. M. and Fleming, P. J. (1993). Genetic Algorithms for Multiobjective Optimization: Formulation, Discussion and Generalization, *Proceedings of The 5th International Conference on Genetic Algorithms*, pp. 416-423.

Hibiki, N. (2001). *Financial Engineering and Optimization [Kinyu Kougaku to Saitekika: in Japanese]*, AsakuraPublishing Co.

Isahaya, H., Osawa, S., Ishiwatari, N., Yoshino, M., Kurashige, O. and Katayama, H. (2009). Factor Analysis on Overseas Offshoring of Japanese Automotive Industry by Logit Model, *The 5th*

International Congress on Logisitics and SCM Systems (ICLS2009), pp. 103-109, Seoul, Korea, 2nd-5th June.

Isahaya, H., Misumi, H. and Katayama, H. (2010). *Structure Analysis of Japanese Automotive Industry and Automotive Parts Industry by Logit Model [Nikkei Kanseisha Gyoukai oyobi Jidoushabuhin Gyoukaino Kouzou Bunseki: in Japanese]*, *The 13th Congress of The Japan Society of Logistics Systems (JSLS2010)*, pp. 141-144, Fukushima University, Fukushima, Japan, 6th June.

Isahaya, H., Ishiwatari N., Yoshino M. and Katayama, H. (2011). A Study on Supply Chain Construction in The Automotive Parts Industry ~An Approach to Design Trading Volume by Portfolio Theory~, *Proceedings of The 6th International Congress on Logistics and SCM Systems (ICLS2011)*, pp. 103-109, Ambassador Hotel Kaohsiung, Kaohsiung, Taiwan, 7th-9th March.

Ishikawa, T., Murata, K., Sera, T., Hayashi, N., Ishiwatari N., Yoshino M. and Katayama, H. (2012). Design of Assembler-Supplier Logistics Network for Car Parts Industry -An Attempt for Sensitivity Analysis on Supply Chain Portfolio-, *Proceedings of the 5th International Supply Chain Management Symposium and Workshop (GSCM2012)* in CD-ROM, Kojima Hall, University of Tokyo, Tokyo, Japan, 8th-10th March.

Ishikawa, T. and Katayama, H. (2012). Sensitivity Analysis on Supply Chain Portfolio for Car Parts Industry-An Attempt for Construction of Disaster Management Procedure-, *Proceedings of the 7th International Congress on Logistics and SCM Systems (ICLS2012)* in CD-ROM, KOFST International Convention Center, Seoul, Korea, 7th-9th June.

Katayama, H., Soshiroda, M. and Muramatsu, R. (1988). Analysis of Periodic Reordering System with Plural Moving Average Demands, *Journal of Japan Industrial Management Association (JIMA)*, Vol. 39, No. 4, pp. 218-225.

Katayama, H., Isahaya, H. and Hwang, R. K. (2009). Supply Chain Offshoring of Japanese Car Industries in China and Evaluation of Its Driving Factors by Logit Analysis, *Proceedings of the 14th Annual Cambridge International Manufacturing Symposium,* pp. 73-86, Møller Centre, Cambridge, UK, 24th-25th September.

Katayama, H., Isahaya, H., Ishikawa, S. (2011). Supply Chain Portfolio: an Essay, Proceedings of the *14th Annual Congress of The Japan Society of Logistics Systems (JSLS2011)*, pp. 65-70, Tokyo Legal Mind University, Tokyo, Japan, 11th-12th June.

Katayama, H. (2012). Models of supply chain portfolio for industrial risk management, *Proceedings of the 16th Annual Cambridge International Manufacturing Symposium,* 13 pages in website, Møller Centre, Cambridge, UK, 20th-21st September.

Luenberger, D. G., Imano, H., Hibiki, N. and Suzuki, K. (2002). *Introduction to Investment Science*, Nihonkeizai Inc., Tokyo, Japan.

Uchiyamada, T. (2008). Toyota's Manufacturing [Toyota no Monodukuri: in Japanese], *Nikkei Monozukuri*, April. (http://techon.nikkeibp.co.jp/article/COLUMN/20080421/150743/)

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Development of Assignment Model for Strategic Visual Management Technology Transfer

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Abstract
Manufactures have an important issue which is an effective reuse of lean technologies for resolving various problems, in order to improve their competiveness continuously. As countermeasure of it, most of the companies have developed the case-base system for retrieving and reusing relevant cases. However how to utilize the case-base depends on an ability of each user and a development of the methodology to utilize the case-base is not enough. Visual management (VM) technology, one representative lean technology, is forced on all in this paper. And then, an assignment model of useful technologies to multi-site factories within a company is developed by mathematical programming. In the proposed model, a contribution degree of each technology to each key performance indicator is measured by Analytic Hierarchy Process (AHP). Also, a confirmation of the utility of the proposed model is performed through a simple case study with collaborative firm.

Keywords: Multi-site Factory Management, Lean Strategy, Technology Intelligence, Visual Management, Mathematical Programming, Analytic Hierarchy Process (AHP).

1. Introduction

Effective reuse of lean technologies to improve a capability of production system is one important issue for manufacturing companies where various values are delivered to their customers. Each company has accumulated developed cases in lean management as electric media to retrieve and reuse them. However how to utilize the case-base depends on expert's experience or intuition and is not strategic activity. A cause of the situation is not to clarify the relationship between lean technologies accumulated in a case-base and burdens which each factory has. Based on the problem recognition, in order to deliver one material for promoting a reuse of lean technologies, this paper tackles with an assignment model of visual management (VM) technologies (Watanabe 2002) as one useful lean technologies by mathematical programming. And then, through a simple case study with collaborative firm, the utility of the proposed model is confirmed.

2. Literature Review

2.1 Data database for lean management
Two databases have been developed to promote lean management. First one is lean case-base which supports Do-step in PDCA cycle. It is a database for delivering useful technologies to the activity (Murata and Katayama 2009b, 2010a, b). The other one is Key Performance Indicator (KPI) database which supports Plan-step, Check-step and Action step in PDCA cycle (Lillrank and Kano 1989). KPI data is accumulated in the database to analyze the result of activity and make next action plan (Murata and Katayama 2009a). In the research process

of them, a framework and a procedure to construct and utilize them is developed in single site factory. However a methodology to realize systematic technology transfer among multi-site factories is not developed.

2.2 Deployment of knowledge/technology in TPM activity

Total Productive Maintenance/Management (TPM), one of the representative lean schemes, has three expansion types such as geographical deployment, horizontal deployment and vertical deployment (Katayama 2008). Murata and Katayama (2008) show a kind of technology transfer in TPM as the survey result on several factories located in Europe and Japan. The technology transfer is performed among three type's players such as 1) an expert outside a company, 2) an expert in a company and 3) an expert candidate in a company. Therefore, the technology transfer among them is six kinds as shown in Table 1. In particular, the proposed model in this paper supports an activity of type d.

Table 1. Technology transfer among three players in TPM activity

To \ From	1)	2)	3)
1)	a)	b)	c)
2)	–	d)	e)
3)	–	–	f)

<A kind of players>

1) experts outside a company
   They have relevant knowledge and experience in the various types of industries.
   (Ex. consultant, professor)

2) experts in a company
   They have relevant knowledge and experience in their factory
   (Ex. promoter of total improvement project in a company, leader of individual improvement project)

3) expert candidates in a company
   They have knowledge and experience of their operation.
   (Ex. members of individual improvement project)

<A type of technology transfer in TPM>

a) among experts outside a company
   Outline: Technologies developed in the consulted and educated companies are shared among them.
   Methodology: A study meeting and a training session in their organization where they belong to. (Observed case of company A: a study group to consultation skills)

b) and c) from experts outside a company to experts in a company and expert candidates in a company

Outline: Experts outside a company teach members of a company how to progress an activity and a point of the problem solving by lean technology and so on.

Methodology: Promoted by an organization outside a company such as consulting firm and an educational institution, a technical guidance and a screening system are performed in the consulted company. Also, an education program and exhibitions of lean management are performed outside a company. (Observed case of company B: concrete consultant teaches a purpose of an improvement project, how to promote a project and how to visualize a progress of a project.)

d) among experts in a company

Outline: They introduce developed useful cases each other. Especially high quality cases evaluated from the company where they belong are sheared among multi-site factories.

Methodology: A meeting by them and a database of lean case (Observed case of company C: DVD for an education of lean technologies' mechanism is made)

e) from experts in a company to expert candidates in a company

Outline: Expert supports to solve burdens which expert candidates tackle with.

Methodology: An advice and a coaching in a regular meeting of the activity (Observed case of company D: a short course of 5why-analysis)

f) among expert candidates in a company

Outline: They share and exchange their knowledge and experience on the way to develop lean technologies each other.

Methodology: A discussion among them and a competition of useful cases under the promoted by experts in a company (Observed case of company E: cross discussion with affiliated companies)

3. Research Procedure

Research Procedure of this paper consists of three steps as follows.

Phase 1: Design of the extended supply chain framework
Before the description of the proposed model, the place where its capability is displayed is clarified through the consideration of one trial of extended supply chain management.

Phase 2: Formulation of assignment model of lean technologies
The purpose of the proposed model supports that each factory selects useful cases to improve performance indicators from the case-base. In the model building, the problem to assign cases accumulated in developed case-base to multi-site factories is considered as a linear programming problem.

Phase 3: Evaluation of cases to performance indicators
Analyzed data of the proposed model is made by analytic hierarchy process (AHP). Each data means a contribution value of each case to each performance indicator. Dataset express a table form. In the form, the vertical axis is case number and the horizontal axis is an attributes of performance indicators such as quality, delivery and cost and so forth.

Phase 4: Confirmation of the utility of the proposed model
An initial experimentation of the case selection by the proposed model is performed in this step. It is supported by the collaborate company. The selection result is evaluated through a discussion with lean experts of the collaborated company.

4. Knowledge Supply Chain

The proposed model in this paper is utilized for effective technology transfer. It should be realized everywhere in supply chain. Formerly, for example, supply chain management means as follows (Christopher 2011);

The management of upstream and downstream relationships with suppliers and customers in order to deliver superior customer value at less cost to the supply chain as a whole.

It is *a player oriented supply chain* and consists of functions in the main activity of a value chain (Porter 1985) like a maker, a wholesaler and a retailer as shown in Figure 1. Particularly, in the age of the globalization, a coordination of supply chain has been difficult in order that a geographical expansion is installed to a conventional supply chain.

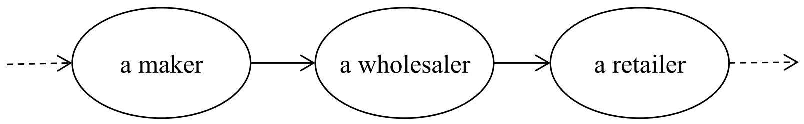

Figure 1. A flow of conventional supply chain (main activity of value chain)

The delivered item in the system is physical something such as goods, materials, a traffic system and passengers and so forth. However, the object of the technology transfer is different. It is "knowledge". Of course, a type of knowledge is various through a lot of relevance discussions and study are performed. Both conventional supply chain management and technology transfer are the same function from the viewpoint of supply chain. Therefore, the latter activity is named "knowledge supply chain" in this paper. It is considered a time-series oriented supply chain such as among a number of activity times and among generations as shown in Figure 2. It will be expected to resolve the problem focused in this study which is a succession of valuable knowledge and skills experts have in advanced nations.

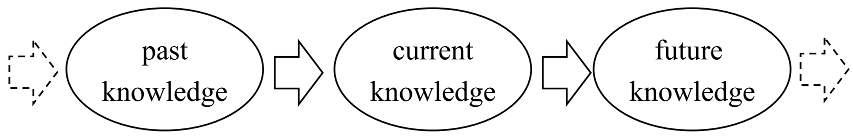

Figure 2. A flow of knowledge supply chain

Figure 3 shows one graph of a combination of two kinds of supply chain. A common point between them is a realization of effective chain management which is to connect a relationship between individual neighbor chains smoothly and to manage a total chain effectively. In order to develop a conventional supply chain continuously, it is important to construct knowledge supply chain system. And then, a reconsideration of a conventional supply chain system is necessary to perform knowledge supply chain management smoothly. The proposed model in this paper contributes to construct knowledge supply chain in case of multi- site factories which a company has over the world.

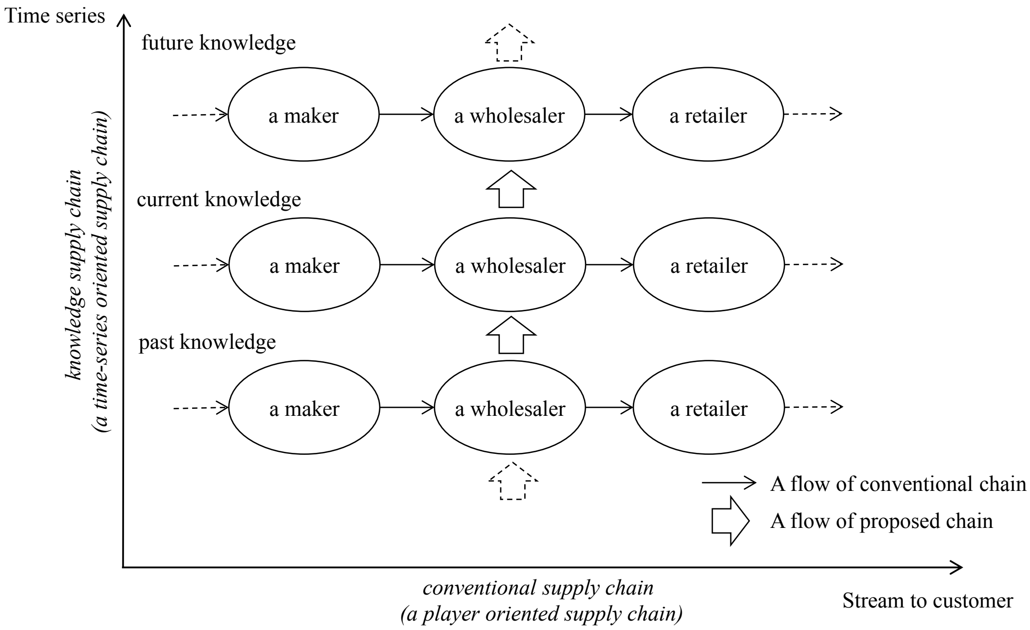

Figure 3. A combination flow of two kinds of supply chains

5. Proposed Model

The proposed model in this paper is utilized for effective technology transfer. It should be realized everywhere in supply chain. Formerly, for example, supply chain management means as follows (Christopher 2011);

A mathematical representation is given by the following formula (1)-(7).

Objective function:

$$\max J = \sum_{j=1}^{p} y_j \tag{1}$$

（Maximum of the contribution of all factories to all performance indicators）

Subject to,

$$y_j = \sum_{i=1}^{n} b_{ij} x_{ij} \tag{2}$$

（Contribution of factory *j* to all performance indicators）

$$b_{ij} = \sum_{h=1}^{m} (1 + A'_{hj}) w_{hi} \tag{3}$$

（Contribution of factory *j* to all performance indicators in case of installation of case *j*）

$$A_{hj} = \frac{\sum_{h=1}^{m} \sum_{j=1}^{p} a_{hj}}{a_{hj}} \tag{4}$$

(Necessity to improve indicator h in factory j (before standardization): It is considered from the viewpoint of technology transfer. In case of the model, the definition is a reciprocal of a ratio of a number of cases for each performance indicator improvement in each factory to a number of all cases registered in the case-base)

$$A'_{hj} = \frac{A_{hj}}{\sum_{h=1}^{m}\sum_{j=1}^{p} A_{hj}} \tag{5}$$

(Necessity to improve performance indicator h in factory j (after standardization): If the necessity to improve object indicator is high, the value is large.)

$$lc_j \leq \sum_{i=1}^{n} x_{ij} \leq uc_j \tag{6}$$

(Constrains of a number of installed cases to factory j: For the condition of cost and time to install a case in each factory)

$$ls_i \leq \sum_{j=1}^{p} x_{ij} \leq us_i \tag{7}$$

(Constrains of a number of factory to install case i: For the condition of technology diversification to resolve various burdens)

＜Decision variables＞

x_{ij} ：If factory j installs to case i, x_{ij} is 1.

If factory j doesn't installs to case i, x_{ij} is 0.

＜Fixed numbers＞

w_{hi} ：Contribution of case i to performance indicator h $(h = 1,\ldots,m, i = 1,\ldots,n)$

a_{hj} ：A number of cases for performance indicator h improvement in factory j $(h = 1,\ldots,m, j = 1,\ldots,p)$

uc_j ：Upper limit of a number of installed cases to factory j $(j = 1,\ldots,p)$

lc_j ：Lowest limit of a number of installed cases to factory j $(j = 1,\ldots,p)$

us_i ：Upper limit of a number of factories where case i is installed $(i = 1,\ldots,n)$

ls_i ：Lowest limit of a number of factories where case i is installed $(i = 1,\ldots,n)$

m ：Suffix of a total number of performance indicators

n ：A total number of cases

p ：A total number of factories

h ：Suffix of performance indicator

i ：Suffix of case

j ：Suffix of factory

6. Case Study

6.1 Analyzed object

The condition of VM case, performance indicator and factory is as follows.

1) VM case
One-hundred and forty-one VM cases were collected via investigation of four chemical plants in one collaborated company. These are the members of the case-base. For the preparation of VM case analysis, 10 typical cases involving different VM technologies from the case-base were selected by experts. The case numbers are 14, 24, 28, 54, 58, 63, 97, 117, 121 and 140 as shown in Table 2.

Table 2. Profile of object case-base and representative cases

Group	A number of cases	Representative case
Group 1	8	case14
Group 2	13	case 24
Group 3	16	case 28
Group 4	27	case 54
Group 5	11	case 58
Group 6	29	case 63
Group 7	17	case 97
Group 8	7	case 117
Group 9	5	case 121
Group 10	8	case 140

2) Performance indicator
Object performance indicator is seven performance indicators; quality (Q), cost (C), delivery (D), productivity (P), safety/hygiene (S/H), environment (E) and morale (M). Definition of each performance indicator is as follows.

Quality (Q): This is critical for improving the KPI related to the operation, inspection and prevention for manufacturing the required product quality.

Cost (C): Similar to the previous KPI, this is related to a reduction of failure cost and maintenance and improvement of job skills.

Delivery (D): Similar to the previous KPI, this is related to the efficient delivery of products/materials from/ to the plant and safe drainage of accumulated rainwater.

Productivity (P): Similar to the previous KPI, this is related to the maintenance and improvement of the standard operation time and effective job skills transfer.

Safety/hygiene (S/H): Similar to the previous KPI, this is related to quick information concerning the cause of a disaster such as a power failure or a fire.

Environment (E): Similar to the previous KPI, this is related to 5S (Seiri, Seiton, Seiso, Seiketsu and Shitsuke), conservation of utilised energy in the factory, and safe drainage of accumulated rainwater.

Morale (M): Similar to the previous KPI, this is related to the communication of basic knowledge concerning operation and maintenance and information on the present condition of the faculties/equipment in the plant.

3) Factory
Object factory is four factories which one company has; factory A, factory B, factory C and factory D.

6.2 Analyzed data
1) Contribution of lean case to performance indicator
This section consists of three steps followed by the AHP methodology. In the first step, construction of the AHP hierarchy is performed based on the three defined terms, which are the objective, criterion, and alternative, as shown in Figure 4. The objective of the hierarchy is evaluation of the contribution of the VM case for improving KPIs by a lean expert. The criteria of the hierarchy are seven performance indicators mentioned above. The alternative of the hierarchy is the 10 selected VM cases in the previous section.

In the second step, two pairwise comparison analyses are performed based on the constructed hierarchy. Table 3 shows the rating scores for each of the seven performance indicators with respect to the objective. Table 4 shows the rating scores of the 10 VM cases with respect to quality (Q) as one example of the seven KPI ratings. Each rating scale has five ranks, 5.00, 3.00, 1.00, 0.33 and 0.20.

For instance, in the pairwise comparison between the two cases shown in Table 4, the score of case 14 to case 58 is 5.00 because there is a large difference between the contributions of the two cases to maintaining the quality of the product. The reason for this is that case 14 directly contributes to maintaining the quality of the product. Case 58 mainly contributes to maintaining the safety of operators and the work environment, not the quality of the product. On the other hand, case 97 indirectly contributes to maintaining the quality of the product by educating operators. Therefore, the score of case 14 to case 97 is 3.00. The other six cases, except for cases 58 and 97, directly contribute to maintaining the quality of the product like case 14. Therefore, the scores of case 14 to the six cases are 1.00.

In the third step, evaluation of the ratings of the 10 VM cases with respect to the objectives is performed by the rating scores derived in the previous step. The scoring results standardized between zero and one, are illustrated in Table 5.

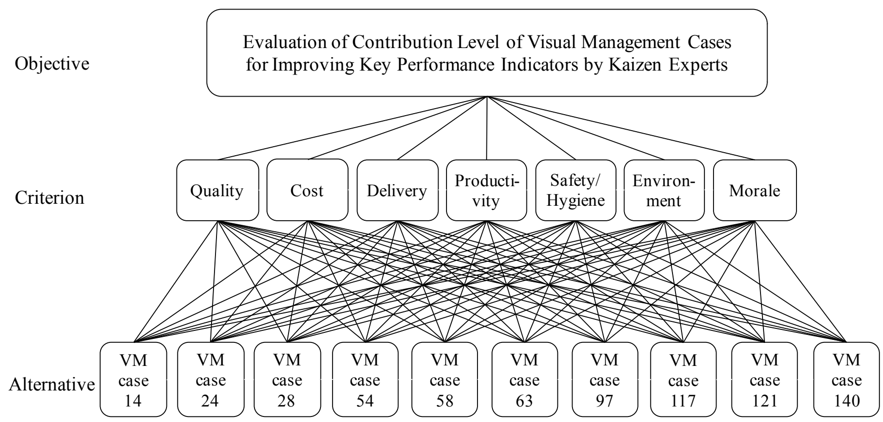

Figure 4. AHP hierarchy for the proximity evaluation of VM cases to PIs

Table 3. Rating scores for each PI

(a) \ (b)	Q	C	D	P	S	E	M
Q	1.00	5.00	1.00	3.00	1.00	1.00	1.00
C	0.20	1.00	0.33	1.00	1.00	1.00	1.00
D	1.00	3.00	1.00	3.00	1.00	3.00	1.00
P	0.33	1.00	0.33	1.00	1.00	0.33	1.00
S	1.00	1.00	1.00	1.00	1.00	1.00	0.33
E	1.00	1.00	0.33	3.00	1.00	1.00	1.00
M	1.00	1.00	1.00	1.00	3.00	1.00	1.00

Rating score:
5.00: Contribution of VM case for improving PI (a) is much higher than PI (b).
3.00: Contribution of VM case for improving PI (a) is higher than PI (b).
1.00: Contribution of VM case for improving PI (a) is as high as PI (b).
0.33: Contribution of VM case for improving PI (a) is a little lower than PI (b).
0.20: Contribution of VM case for improving PI (a) is lower than PI (b).

Table 4. Rating scores each case related to quality (Q)

(s) \ (t)	14	24	28	54	58	63	97	117	121	140
14	1.00	1.00	1.00	1.00	5.00	1.00	3.00	1.00	3.00	1.00
24	1.00	1.00	0.33	1.00	3.00	1.00	3.00	1.00	3.00	3.00
28	1.00	3.00	1.00	1.00	3.00	1.00	3.00	1.00	3.00	3.00
54	1.00	1.00	1.00	1.00	3.00	3.00	3.00	1.00	3.00	1.00
58	0.20	0.33	0.33	0.33	1.00	0.33	0.33	0.33	1.00	0.33
63	1.00	1.00	1.00	0.33	3.00	1.00	0.33	0.33	1.00	0.33
97	0.33	0.33	0.33	0.33	3.00	3.00	1.00	1.00	1.00	1.00
117	1.00	1.00	1.00	1.00	3.00	3.00	1.00	1.00	1.00	1.00
121	0.33	0.33	0.33	0.33	1.00	1.00	1.00	1.00	1.00	0.33
140	1.00	0.33	0.33	1.00	3.00	3.00	1.00	1.00	3.00	1.00

Rating score:
5.00: Contribution of VM case (s) for improving quality is much higher than the VM case (t).
3.00: Contribution of VM case (s) for improving quality is higher than the VM case (t).
1.00: Contribution of VM case (s) for improving quality is as high as the VM case (t).
0.33: Contribution of VM case (s) for improving quality is a little lower than the VM case (t).
0.20: Contribution of VM case (s) for improving quality is lower than the VM case (t)

Table 5. Contribution values of cases to PIs calculated by AHP (W_{hi})

Case \ PIs	Qulaity	Cost	Delivery	Productivity	Safety	Environment	Morale
14	0.025	0.008	0.015	0.005	0.007	0.008	0.010
24	0.026	0.003	0.013	0.015	0.019	0.006	0.007
28	0.033	0.006	0.027	0.010	0.010	0.019	0.015
54	0.027	0.007	0.039	0.012	0.013	0.022	0.014
58	0.007	0.022	0.010	0.003	0.030	0.014	0.028
63	0.014	0.003	0.014	0.006	0.005	0.007	0.009
97	0.015	0.008	0.012	0.004	0.006	0.006	0.033
117	0.022	0.011	0.036	0.010	0.011	0.020	0.011
121	0.010	0.010	0.014	0.009	0.005	0.012	0.009
140	0.020	0.015	0.031	0.010	0.012	0.021	0.025

2) Contribution of lean case to performance indicator

A_{hj} : The values of Table 6 by formula (4) and (5).

uc_j : 3 (the same values of all factories)

lc_j : 1(the same values of all factories)

us_i : 2 (the same values of all factories)

ls_i : 1 (the same values of all factories)

Table 6. Necessity to improve each indicator in each factory (A_{hj})

Factory / PIs	Factoy A	Factory B	Factory C	Factory D	Total
Q	0.006	0.005	0.006	0.008	0.025
C	0.028	0.021	0.042	0.012	0.103
D	0.084	0.084	0.028	0.028	0.224
P	0.028	0.012	0.006	0.017	0.063
S	0.084	0.042	0.017	0.028	0.171
E	0.084	0.084	0.042	0.042	0.252
M	0.084	0.028	0.042	0.008	0.162
Total	0.398	0.276	0.183	0.143	1.000

6.3 Calculation result

Table 7 shows the calculation result by the proposed model.

Table 7. Assignment result of each factory

Factory / Case No.	Factoy A	Factory B	Factory C	Factory D	Total
14	0	0	1	1※	2
24	0	0※	1	0	1
28	1	0	1※	0	2
54	0※	0	0	1	1
58	0	0	0※	1	1
63	1	0	0※	0	1
97	1	0	0	0※	1
117	0	1※	0	0※	1
121	0	1	0※	0※	1
140	0	1	0	0※	1
Total	3	3	3	3	12

※···A number of factory X's cases registered in the case-base is the most of four factories. (Ex. A number of factory B's cases similar to case 117 and case 120 is the most of four factories.)

6.4 Discussion

Three cases, case 28, case 63 and case 97, is selected to improve the capability of factory A. The factory has the highest score of A_{hj} of the all factories as shown in Table 6. Particularly, case 97 has the highest contribution to morale. And the related indicator is one of the performance indicators which should be mainly improved in factory A. One weak point of the factory will be expected to improve by the installation of the case.

Also, A_{hj} of factory D is the lowest of the all factories. In particular, the necessity to improve environment indicators is the highest of the all performance indicators in the factory. In order to correspond to improve the indicator, case 54 is selected, which is the most contribution case to improve the indicator. These facts mentioned above indicate that the effective improvement of performance indicators can be realized by an installation of cases to each factory.

Furthermore, most of the factories are not sufficient development of case which the proposed model selects in order to improve relevant indicators. It contributes to diversify the factories technology.

Based on the findings mentioned above from the calculation results by the proposed model, the utility of it will be confirmed from the viewpoint of delivering the materials for the strategic technology transfer.

7. Concluding Remarks

In this paper, the assignment model of lean technology is proposed to resolve burdens of multi-site factories. And then, the utility of the proposed model is confirmed by the case-base of VM technology in collaborative firm. The main future work is to actually install selected case by the proposed model and to confirm its effects.

Reference

Christopher, M. (2010). *Logistics and supply chain management (fourth edition)*, Financial Times Press.

Katayama, H. (2008). "Requisites and for Lean Technology Transfer and its Infrastructure Construction: A Case of Global Transfer of TPM scheme – Lean Gijytu Iten no tameno youken to infura seibi ni kansuru kousatu: TPM sukimu no gurobaru iten wo kesu tosite", *Proceedings of the 11th conference of the Japan Society of Logistics System*, 2008.

Lillrank, P. and Kano, N. (1989). *Continuous Improvement - Quality Control Circles in Japanese Industry*, University of Michigan, Ann Arbor, Michigan.

Murata, K. and Katayama H. (2008). "A Study on Organizational Deployment of Lean Technology: Investigation of TPM factories in Japan and Europe", *Proceedings for the 20th anniversary of the Society of Plant Engineers Japan Founding*, 33-36, Pacifico Yokohama, Yokohama, Japan, 1st-2nd, December [in Japanese].

Murata, K. and Katayama, H. (2009a). "An Evaluation of Factory Performance Utilized KPI/KAI with Data Envelopment Analysis", *Journal of the Operations Research Society of Japan (JORSJ) (A Special Issue on Operations Research for Performance Evaluation)*, 52/2, 204-220.

Murata, K., Suzuki, F., Honda, Y. and Katayama, H. (2009b). "Visual Management Development with Related Technology Assets: Case Study on Chemical Plant", *Proceedings of the 14th Cambridge Symposium on International Manufacturing: Configuring Manufacturing Value Chains: Responding to an Uncertain World*, 164-178 in CD-ROM, Moeller Centre, Churchill College, University of Cambridge, Cambridge, United Kingdom, 24th-25th September.

Murata, K. and Katayama, H. (2010a). "Development of Lean Case-base for Effective Technology Transfer: A Case of Visual Management Technology", *International Journal of Production Research (IJPR)*, 48/16, 4901-4917.

Murata, K. and Katayama, H. (2010b). "A Study on Construction of Lean Case-base and Its Utilization: A Case of Visual Management in Fabrication and Assembly Shop-floors", *International Journal of Production Research (IJPR)*, 48/24, 7265-7287.

Porter E. M. (1985). *Competitive advantage: creating and sustaining superior performance*, Free Press.

Watanabe, T. (2002). *Best Practice of Manufacturing Innovation: Visual Management Technique – Genba Kakushin no Best Practisu: Jixtusen Me de Miru Kanri Technixtuku*, Japan Institute of Plant Maintenance (JIPM), 2002 [in Japanese].