ISBN: 978-1-902546-45-2

PRESENTATIONS | THURSDAY 11 SEPTEMBER

Life after the patent cliff
Peter McDonnell, Senior Technical Director, **Sanofi-Genzyme**

Global network considerations in a distributed business
Tim Flaherty, Operations General Manager, **Caterpillar**

Manufacturing footprint for Grundfos Serbia including establishment of networks and supply chain
Knud Krægpøth, SVP Corporate Supply Chain, **Grundfos**

eCommerce - changing shopper habits and the impact on international manufacturing
Dhivant Patel, Global e-Commerce Supply Chain, **Unilever**

Risk and resilience of global supply networks
Nigel Strutt - UK Director, Supply Chain Strategy, **Lockheed Martin, UK**

A vision for future manufacturing enterprises
Jeffrey Tew, Chief Scientist TCS, **TATA**

Squeezing improvements: innocent's outsourced supply chain journey
Stephen Spall, Group Operations Director, **Innocent Drinks**

The manufacturing location decision - where's the value now?

Professor Lisa M. Ellram
Co-editor-in-chief, Journal of Supply Chain Management; James Evans Rees Distinguished Professor of Supply Chain at the Farmer School of Business, Miami University

Supply chain evolution - an emerging science

Professor Bart L. MacCarthy
European Editor, The International Journal of Production Economics; Professor of Operations Management, Nottingham University Business School

Academic panel discussion

'Publishing and special issue opportunities for research on new supply chains and global value networks'

RESEARCH THEMES | SESSION ONE: 10.30

Sustainable supply chains (Chair: Mukesh Kumar)
The adaptation of supply networks to climate change
Andre Kreie[1] and Christine Rutherford[2], [1]Kuehne Foundation, Switzerland, [2]Heriot-Watt University, UK
Supply chain resilience for Oil & Gas industry infrastructure projects
Ankan Mitra[1], Pep Borromeo[2] , [1]ABB Global Industries and Services Ltd, India [2]ABB Ltd, UK
Greening manufacturing supply chains in Asia's emerging economies: A conceptual framework
Ruoqi Geng[1], Afshin Mansouri[1] and Emel Aktas[2] ,[1]Brunel University London, UK, [2]Cranfield University, UK

Internationalisation (Chair: Afonso Fleury)
International manufacturing networks: how changes at strategic level impact their design and management
Afonso Fleury[1], Yongjiang Shi[2], Silas Ferreira Junior[1], Jose H. D. Cordeiro[1], [1] University of São Paulo, Brazil, [2] University of Cambridge, UK
Home network positions and the impact on internationalization
Du Jian[1], Chang Xiaoran[1], Xu Yue[2], [1]School of Management, Zhejiang University, China, [2]Hull University Business School, UK
Customer-driven Planning and Control of Global Production Networks – Balancing Standardisation and Regionalisation
Tobias Arndt, Jan Hochdoerffer, Emanuel Moser, Steven Peters, Gisela Lanza, Karlsruhe Institute of Technology (KIT), Institute of Production Science (wbk)

Network structures (Chair: Petri Helo)
Order-decoupling point and global value network architectures
Petri Helo, University of Vaasa, Finland
Identification of Autonomous Structures in Dynamic Manufacturing Networks using Clustering Approaches
Till Becker and Daniel Weimer, BIBA, University of Bremen, Germany
A Future Supply Chain Assessment Framework: a case study of Terpene-based Supply Chain
Mukesh Kumar, Wouter Bam, Jag Srai, University of Cambridge

Global manufacturing & China - 1 (Chair: Yongjiang Shi)
An Overview of Chinese Manufacturing Development in the last Ten Years: to celebrate the 10th GMC Symposium
Xiaobo Wu[1], Yongjiang Shi[2], Peizhong Zhu[1, 2], [1]Zhejiang University, China; [2] University of Cambridge, UK
Are Chinese firms' outward foreign direct investments (OFDIs) a kind of herd behavior? Empirical evidence from an institutional isomorphic perspective
Gangxiang Xu, Zhejiang University
The Motivations and Practices of MNCs' Overseas R&D Activities: A Comparative Analysis
Quan Zhou[1,2], Yongjiang Shi[1] ,Xiaobo Wu[2], [1]University of Cambridge, UK, [2]Zhejiang University, China

Corporate lean partnerships: special track (Chair: Torbjorn Netland)
Lean Operations Management and its Evolution –A Japanese Perspective
Professor Hiroshi Katayama, Waseda University
Critical Factors in Designing of Lean and Green Equipment
Zahra Mohammadi, Sasha Shahbazi and Martin Kurdve, Mälardalen University Sweden
Calibrating the expectation from corporate lean programs
Torbjorn Netland, Norwegian University of Science and Technology

Off-shoring & re-shoring (Chair: Jag Srai)

Offshoring trends in the manufacturing process within the automotive industry

Steve Simplay[1] and Zaza Nadja Lee Hansen[2], [1]Coventry University, UK [2] Technical University of Denmark, Denmark

Re-shoring UK Manufacturing Activities, Supply Chain Management & Postponement Issues

Hamid Moradlou and Chris Backhouse, Loughborough University, UK

Re-shoring & Offshoring trends: Managing Engineering Multinationals - A comparison of offshoring and outsourcing strategies in UK and German multinational corporations.

Anthony Mitchell, University of Hertfordshire, UK

Network design & strategy (Chair: Harri Lorentz)

Configuring Large Scale Electrical Energy Supply Chains to Improve Sustainability: Implications for Supply Chain Design

Dr. Laird Burns and Dr. Wes Colley, with Dr. Derald Morgan, University of Alabama in Huntsville

Supply chain adaptation through phases of product innovation life cycles

Matthias Parlings[1] and Katja Klingebiel[2], [1]Fraunhofer Institute for Material Flow and Logistics, Germany, [2]University of Applied Science and Arts Dortmund, Germany

Taxonomy of SME manufacturing strategies in a structurally changing economy

Harri Lorentz[1], Olli-Pekka Hilmola[2] and Jarmo Malmsten[1], [1]University of Turku, Finland, [2]Lappeenranta University of Technology, Finland

Sustainable industrial systems (Chair: Mukesh Kumar)

Environmental Sustainability in the UK and Indian Aerospace Industries: A comparative Study

Mukesh Kumar, Akshay Ogale, Jag Srai, University of Cambridge, UK

Systems thinking capability essential for transformation towards sustainable industrial system

Fernando, L. and Evans, S. , University of Cambridge, UK

Developing sustainability in global value chains: the role of production subsidiaries

Ruggero Golini[1], Jury Gualandris[2] and Matteo Kalchschmidt[1], [1]Università degli Studi di Bergamo, Italy, [2]University College Dublin, Ireland

Global manufacturing & China - 2 (Chair: Yongjiang Shi)

Network Resources, Legitimacy and Competitive Advantages

Zhiyan Wu[1] and Yimei Hu[2], [1]Zhejiang University, School of Management, China, [2]Aalborg Univeristy, Department of Business and Management, Denmark

Nurturing business ecosystem to enable paradigm shift: case of emerging wireless telecommunications industry in China

Yue Zhang[1], Yongjiang Shi[2] and Jiang Yu[1], [1]Chinese Academy of Sciences, [2]University of Cambridge

Synergistic Innovation Modes and Innovation Performance

Siyu Liu, School of Management, Zhejiang University, China

Logistics & distributed networks (Chair: Hermann Kuehnle)

Logistics innovation solutions for re-distributed manufacturing

Laura Purvis[1], Robert Mason[1], Andrew Lahy[2] and Mike Wilson[2], [1]Cardiff Business School, Cardiff University, UK, [2]Panalpina Ltd. UK

Smart Units in Distributed Manufacturing (DM) -Key Properties and Upcoming Abilities

Hermann Kuehnle, Otto-von-Guericke-University Magdeburg, Germany

Service innovation in China: Development and implementation of a logistics platform solution

Dmitrij Slepniov[1] and Jun Jin[2], [1]Aalborg University, Denmark, [2]Zhejiang University, China

Production & supply chain management (Chair: Mathias Knollmann)
Shifting Targets in Manufacturing Control: Development of a Methodology Considering Human Behavior to Avoid the Lead Time Syndrome of Manufacturing Control
Mathias Knollmann, Julia Bendul and Mengting He, Jacobs University Bremen,Germany
An Investigation of Production Changeover Time Reduction in Supply Chain Oriented Manufacturing Plant and Sustainability to Improve the Plant Performance
Khalid Mustafa and Kai Cheng, Brunel University
Lead-Time Hedging and Coordination in Prefab House Construction Supply Chain Management using Game Theory
Yue Zhai, George Q. Huanga, The University of Hong Kong, China

Performance measures (Chair: Till Becker)
Performance measures for evaluating last mile logistic solutions: a multi-stakeholder perspective
Tomás Harrington and Jag Srai, University of Cambridge, UK
Performance Evaluation of Visual Management Case for Effective Technology Transfer
Koichi Murata[1*] and Hiroshi Katayama[2], [1]Nihon University, Japan, [2]Waseda University, Japan
Performance and Time Based Robustness Measures for Dynamical and Multi-variant Manufacturing Systems
Till Becker[1] and Mirja Meyer[2], [1]BIBA, University of Bremen, [2]Jacobs University Bremen

Emerging healthcare networks (Chair: Mark Phillips)
Proposing a virtual operations network to support a business policy for the Medicinal and Aromatic Plants sector
Isabel Duarte de Almeida[1] and J. M. Vilas-Boas da Silva[2,3], [1]Universidade Lusíada, Portugal, [2]Instituto Universitário de Lisboa, Portugal, [3]BIU-UNIDE
Towards a Theory of Industrial System: A Case study on Environmental Sustainability in the UK Medical Device Industry
Mukesh Kumar, Yuto Minakata, Jag Srai, University of Cambridge, UK
Understanding Emergent Industrial Ecosystems in Health Care
Mark A Phillips, University of Cambridge, UK

Value Capture (Chair: Matteo Kalchschmidt)
We do create and capture value, don't we? A conceptual model of purchasing contribution to business performance
Jury Gualandris[1], Legenvre Hervé[2] and Matteo Kalchschmidt[3], [1]University College Dublin, Ireland, [2]European Institute of Purchasing Management, France, [3]Università degli Studi di Bergamo
Foreign invested manufacturing company's components sourcing process in the context of China's processing trade
Mingu Kang[1], Ma Ga (Mark) Yang[2], Mark H. Haney[3] and Kihyun Park[3],[1]Zhejiang University, China, [2]West Chester University of Pennsylvania, USA, [3]Robert Morris University, USA
An exploratory study assessing value chain reconfiguration opportunities in oncology
Tomás Harrington and Ismail Najim, University of Cambridge, UK

Life after the Patent Cliff?

Peter McDonnell, Senior Technical Director, Chemistry and Biotechnology Development, Haverhill, Suffolk, UK
Global Innovation Strategy and External Partnerships Manager, Paris, France

Annual Cambridge Manufacturing Symposium, September 11th 2014.

Disclaimer

- The views expressed in this presentation are those of the author and do not reflect the thinking of Sanofi or its affiliates. The purpose of this presentation is to sponsor debate. The content does not indicate any strategic direction that Sanofi is implementing, unless otherwise stated. Errors and omissions are the author's alone.

Topics

- The current state of the Pharmaceutical Industry
  - History and direction
- Pharmaceutical Manufacturing
  - Today
  - Tomorrow
- Commonly Held Beliefs about Pharma
- Opportunities
  - Example

The current state of Pharmaceutical Industry

- History
  - Pre- 2000s
    - Vertically "integrated" - insular
    - Blockbuster focussed
    - Priorities: Sales & Marketing > R&D >> Manufacturing and Supply Chain
  - Noughties
    - Selected functions outsourced
    - Still hoping for blockbusters…….beginning of patent cliff!
    - Priorities: Sales & Marketing > R&D >> Manufacturing and Supply Chain
- Future
  - Short term
    - More biologics
    - Personalised medicines
    - More complete packages developing – diagnostics, devices, services, *etc.*
  - Long term…….

What has changed in Pharma?

- In 1970s, 1980s and 1990s Pharma could do no wrong
  - Steady stream of new products to meet unmet medical needs
  - Highly respected by public and a highly desirable career
  - Some of the most admired companies in the world
  - Very profitable, even though no company had 6% total market share
  - Lots of "me too" drugs produced

- Since then….
  - Number of new drugs coming through has fallen drastically
  - Costs have risen exorbitantly
  - Mergers and acquisitions have more than decimated the industry workforce
  - Scandals have successively hit the industry
  - Costs of healthcare rising – payers have to care about this!
  - Agencies have become much more risk averse, requiring REMs and Outcome Studies
  - The rise and rise of Shareholder Value

Commonly held beliefs about pharma

- The answer for big pharma is Biotech
- Start-ups are better at discovery
- Pharma manufacturing is high tech.
- Pharma costs are high because of excessive regulation
- Regulators oppose changes to manufacturing
- All of the big disease areas have been solved
- All big Pharma cares about is money
- The Blockbuster Model is Broken

The answer for big pharma is Biotech

- **Biotech is seen as less susceptible to sudden loss of exclusivity**
  - **In EU biosimilars guidance is well established**
  - **In US situation remains unclear with clinical studies required to show bioequivalence**
- **In mammalian cell culture the Product is the Process**
  - **Mammalian cell culture did not exist as a manufacturing platform until about 30 years ago**
  - **Manufacturing science is slowly supplanting the "black arts" approach**
- **Cost to market for biologics is lower, due to greater targetting**
  - **Studies at Tufts and Duke Universities do not support this**
- **Are injections really the preferred route of administration?**
  - **Some progress is being made in delivery systems, but it is very slow**

Start-ups are better at discovery

- **Most start-ups fail**
  - **In fact Government agencies, including universities, NIH, MRC, DARPA, *etc.* are most productive in discovery**
    - Some exceptions include The Wellcome Trust, Bill and Melinda Gates Foundation and other charities are significant
  - **Failed start-ups disappear; failed big Pharma doesn't (at least not immediately)**
  - **Biotech as an industry has only just recouped the total investment made**
    - Until recently more money has been lost by the sector that made
    - Time to approval delays inflow of money, other than through licensing, *etc.*
- **Start-ups that are spin-outs from Govt run operations drive innovation**
  - **This situation is a great risk in the UK, as government priorities switch to support of research in applied science**

Pharma manufacturing is high tech.

- **With some specific exceptions pharma manufacturing is amongst the least developed sector in all industry**
  - **Every other industry would have failed years ago if it was as efficient as pharmaceutical manufacturing**
    - Cost has not been a significant driver under the blockbuster model
    - Industry standards allow poor performance
      - Pharmacopoeial standards for content of active in a dosage form ±10%!
    - The QP system in the EU and Pharmacists perpetuates this notion
      - Routine medical examination is no longer exclusively the domain of doctors in the NHS
- **Reliance on the Patent system promotes this view**
  - **Do patents truly capture innovation in the Pharma industry?**
  - **How do other industries manage to succeed without?**

Pharma costs are high because of excessive regulation

- **Undoubtedly compliance costs are a major contributor to cost, but…**
  - **Other regulated industries compete**
    - Aerospace/defence
    - Foods
    - Auto industry
    - Airlines
  - **Pharma has an almost unique need to claim to be different**
    - Bespoke tracking systems for cold chain distribution validation
      - Fresh trout from New Zealand arrives in food stores without excessive cost
- **Unfortunately high profile cases arise all the time**

Regulators oppose changes to manufacturing

- **This has been true in the past**
  - **Misalignment between reviewers and inspectors**
  - **Lack of alignment of approval pathways – despite nearly 30 years of ICH!**
- **The last decade has seen a drive for change at FDA, with strong support at MHRA**
  - **Quality for the 21st Century, QbD, Continuous processing, ICH Risk based approaches (Q8-11)**
- **Most resistance is internal**
  - **Why do anything different from what has worked before?**
  - **Why provide knowledge when data has been sufficient before?**

All of the big disease areas have been solved

- **Why do we need another drug for lowering cholesterol or reducing blood pressure?**
  - **Most drugs do not work for most people**
  - **Clinical trials are very large to protect the public who get no benefit from a drug suffer no harm**
  - **"The chasm reflects obsolete policies and rules put in place to regulate ignorance, not knowledge." (Peter Huber, 2013)**
- **The need for new ways to perform clinical trials that target the right biochemical pathways in the right patient group is manifest**
  - **Too many people are not receiving treatment**
  - **Double blind trials preclude adaptive designs based upon Bayesian statistics**

All big Pharma cares about is money

- **Financial markets drive Shareholder Value in the short to medium term**
  - **Drug development timelines are typically 12-16 years**
  - **Response to patent cliff has been megamergers**
    - Has any these been of benefit to patients, Governments or other payers?
  - **Cost of a new manufacturing plant is about $41M for a small molecule and about 10 time that for a biologics plant (Grabowski)**
- **Manufacturing has been undervalued in big Pharma**
  - **It becomes critical to companies when quality issues arise (whether outsourced or not)**
  - **The value of modern manufacturing has yet to be released in Pharma**
  - **Margins remain high in the industry**
    - Typical CoGs for originator companies was 26% of sales between 1994 and 2006 and for generics was 52% (Basu)
- **Why would big pharma be in such a risky business if it only cared about money?**

The Blockbuster Model is Broken

- **It is more difficult to find blockbusters now**
  - **It doesn't stop people trying!**
- **Other industries exist and thrive without patent led strategy**
  - **Food and beverages**
  - **Electronics**
  - **Automotive**
    - Pharma manufacturing plants have ten times more indirect:direct (value adding) staff.
    - Value add time in pharma is typically 20%; automotive is 60-70% (Cox)
    - OEE in pharma is 20-30%; in other industries it approaches 90%
- **The opportunities for improvement are therefore huge!**

Example: personalised medicine

- **Exon skipping for Duchenne Muscular Dystrophy**
  - **Caused by genetic error on X-chromosome**
  - **Affects 1 in 3,600 boys**
  - **The defective gene encodes for a protein called dystrophin, a major component of muscle**
  - **Patients generally lose the ability to walk by age 10; average life expectancy is 24.**

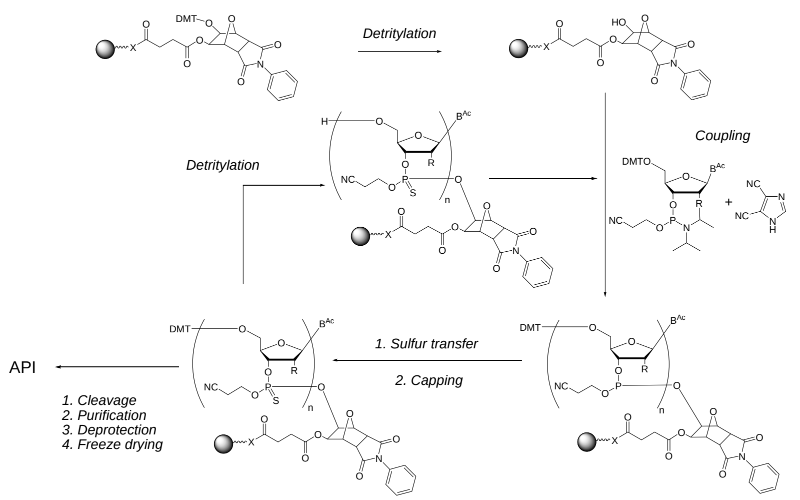
How does it work?

- **DNA unravels so that introns (non protein encoding) and exons (protein encoding) can be copied to pre-mRNA**
- **In a process called spicing the introns are removed giving mRNA, which encodes for the protein**
- **Faulty exons cause transcription (protein manufacture) to stop prematurely, giving shorter protein molecule with less functionality**
- **Using a short synthetic length of RNA can bridge the faulty exon, allowing assembly of longer more functional protein**
- **There are several known mutations that can cause dystrophin to be too short**

Innovative Regulatory Approach

- **There are 79 exons in the dystrophin gene**
  - **13% patients have exon 50 deleted**
  - **A specific sequence of an antisense oligonucleotide can be made to bind to exon 51, allowing the exon skipping to occur**
- **If the mechanism can be shown to work can some other mutations be treated without clinical trials?**
  - **Some mutations at other exons are too rare to perform clinical trials**
  - **Provision at FDA to use such an approach in orphan disease and cancer**

How do you make oligonucleotides?



Equipment

- Benchtop machine
- Fully automated
- Can have PAT for control
- Can add automated purification
- Can make milligrams to grams overnight

How this might work in practice

- Diagnosis (DNA analysis) performed on a chip
- Oligonucleotide of correct sequence is ordered online
- Synthesis and purification run overnight
- Online analysis gives assurance that quality, quantity good
- Correct amount of drug is delivered to patient for immediate use
  - No expensive stock to hold
  - No long stability trials
  - Can be located anywhere
  - Control can be from anywhere
  - Can be transparent to regulators

Questions?

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Managing a Global Manufacturing Network

IfM Cambridge International Manufacturing Symposium
Capturing value from global networks

11 and 12 September 2014
Moller Centre, Cambridge, UK

T S Flaherty, H J Powell Caterpillar Inc.

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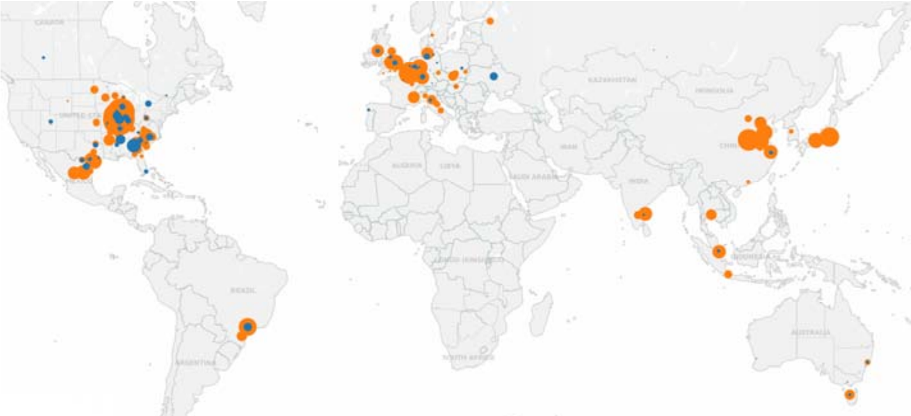
BUSINESS MODEL

Multinational Context

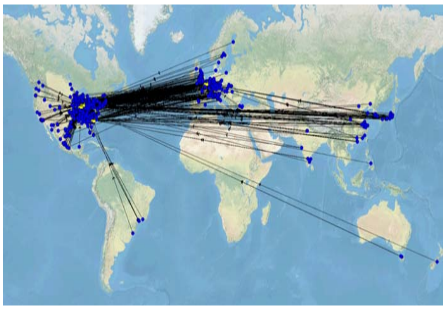
GLOBAL MANUFACTURING NETWORK

Manufacturing Facility
Mfg. Logistics Center



Excludes Service Parts and Dealer Network

Component Manufacturing (Internal Tier1)



INBOUND NETWORK
North America Mfg. Supply Base

OUTBOUND NETWORK
All Component Facilities to Caterpillar Machine Assy. Locations

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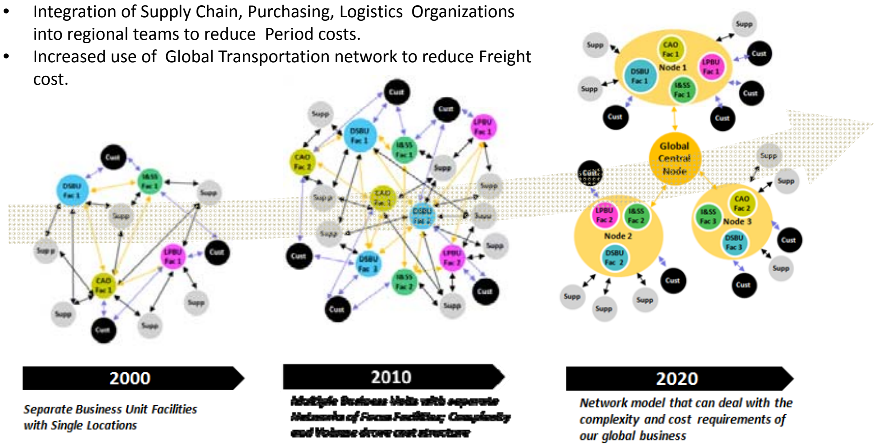
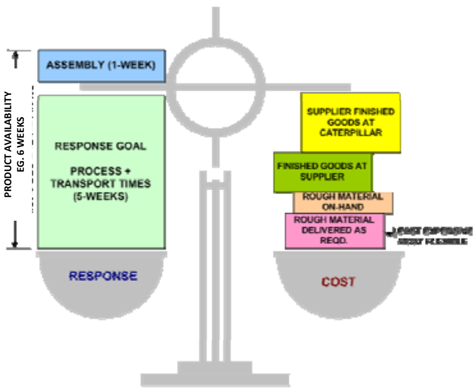
Complexity Management Challenge

- Integration of Supply Chain, Purchasing, Logistics Organizations into regional teams to reduce Period costs.
- Increased use of Global Transportation network to reduce Freight cost.



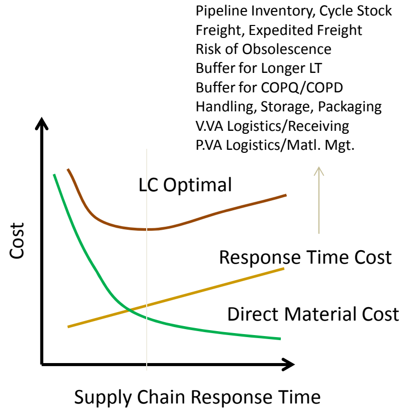
Depiction of the evolution of Complexity in the Component Supply Chain

Lowest Cost vs. Localization



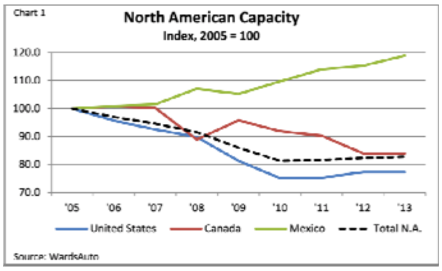
Balancing Response Requirements with Inventory Cost-drivers

H Powell, 2006



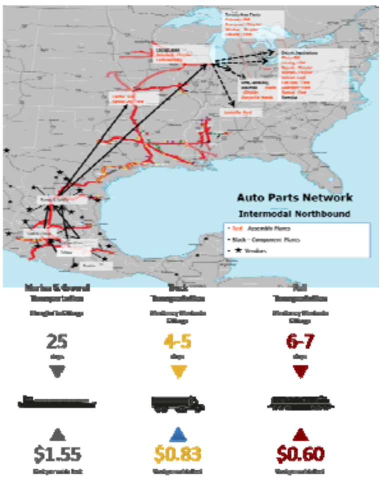
Material Cost Advantage drove Supply-base Off-shoring in USA

USA-Mexico Re-shoring Phenomenon

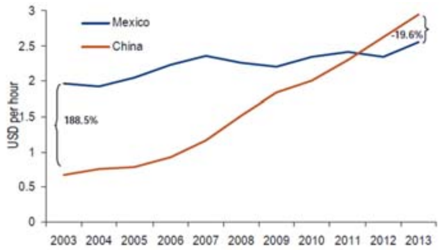


- Significant Increase in Automotive and Automotive T1 Capacity
- Major Investments continue in Mexico and Texas Border Region.
- 2014 Kia, BMW $2Bn

Drivers: Improvements in Labor and Logistics Costs



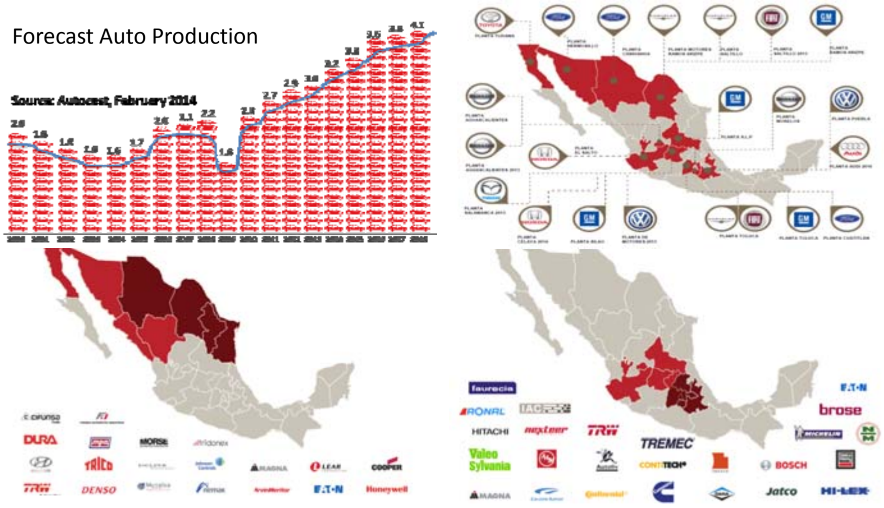
- 2015 Wages in Mexico will be 30% Lower than China
- Mexican labor workforce is highly skilled; Mexico manufacturing is moving from low-skill, high volume products to high-skill, sophisticated products



Continued opportunity in Freight Cost: Perfecting and Maximizing efficient Intermodal Networks

Manufacturing Economic Growth in Mexico

Forecast Auto Production



Caterpillar - Texas

- 26 locations
- 3,000 employees

CAT Work Tools

PROGRESS RAIL SERVICES A Caterpillar Company

Solar Turbines A Caterpillar Company

CAT Logistics

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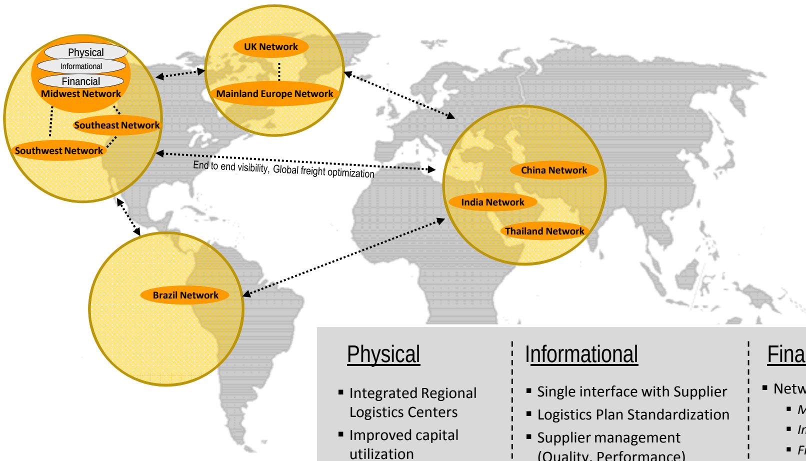
Challenges: Global Network



Physical

- Integrated Regional Logistics Centers
- Improved capital utilization
- Reduced freight moves

Informational

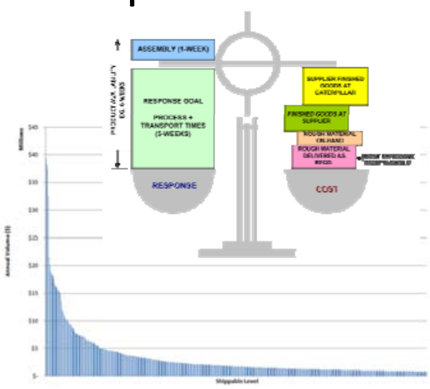
- Single interface with Supplier
- Logistics Plan Standardization
- Supplier management (Quality, Performance)
- Network Inventory control

Financial

- Network manages;
  - *Material cost*
  - *Inventory*
  - *Freight cost*
  - *Packaging cost*
  - *Logistics costs*

Challenges: Operational and Supply Chain Footprint

- Optimizing Response and Inventory to maximize service-level and Shareholder Return (Economic Value-Add, or "OPACC" – Decision basis)
- Manage complexity (Variety and Distribution)



Annual Volume of top 500 shippable parts shown, tail extends to 8,500


THANK YOU
QUESTIONS?
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Manufacturing footprint for Grundfos Serbia including establishment of networks and supply chain

By Knud Krægpøth

be
think
innovate

GRUNDFOS

Knud Krægpøth

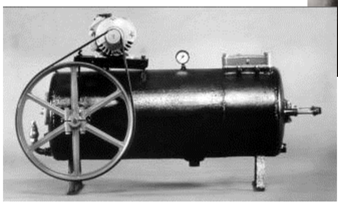
- Engineer with a master in Technology Management
- Joined Grundfos in 1991
- Senior Vice President for Corporate Supply Chain

be think innovate

GRUNDFOS

Grundfos in brief

- Founded in 1945 by Poul Due Jensen
- Annual production of more than 16 million pump units
- Turnover of DKK 23 billion in 2013
- More than 18,500 employees worldwide
- 5% of sales turnover is used on research and development

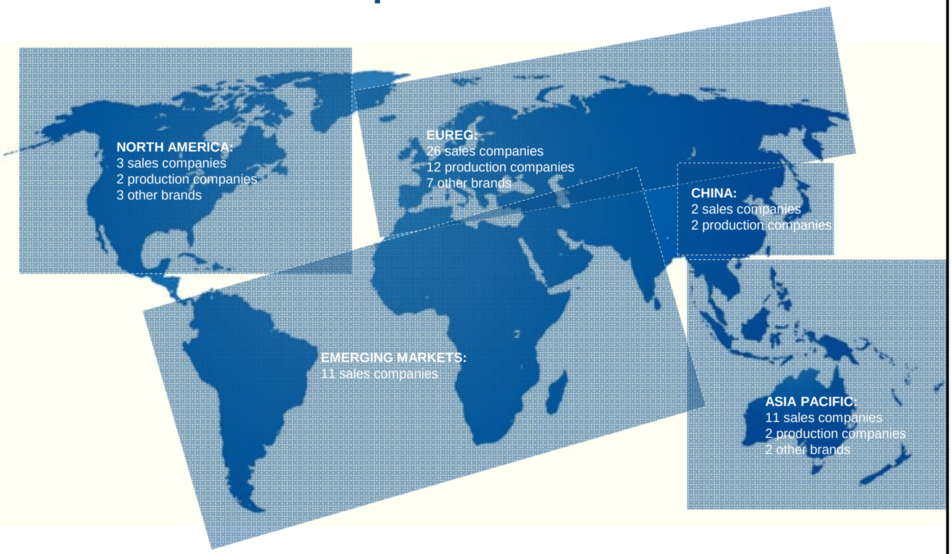


Grundfos in brief

- **Grundfos primarily manufactures:**
  - Circulator pumps
  - Water booster pumps/systems
  - Submersible pumps
  - Industrial pumps
  - Dosing pumps

- The world's largest manufacturer of pumps and pump systems
- Production and sale of electronic motors
- Development, production and sale of electronics for the control of pumps and pump systems
- Development, production and sale of New Business products

Grundfos World Map



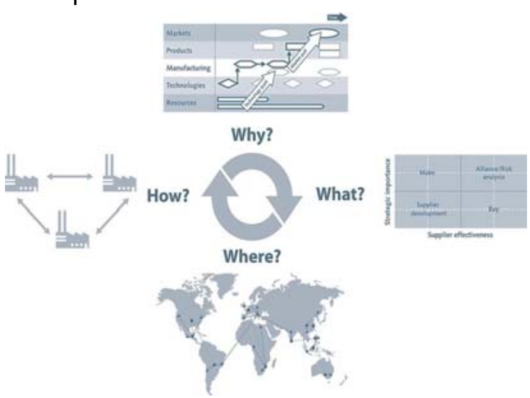
Our history with Cambridge – starting point

- Briefing day January 2008 with Institute for Manufacturing, Cambridge University (Paul Christodoulou and Don Fleet)
- Pilot for production footprint of one product line
- Planning started and the workshop was held August 2008
- The challenge was/is to find the right balance

The Pilot footprint at Grundfos

The Pilot

- The process was run by Paul Christodoulou and Don Fleet
- Interview with 25 stakeholders
- 2 site visits to experience the production lines and culture
- 2½ day workshop with 15 main stakeholders

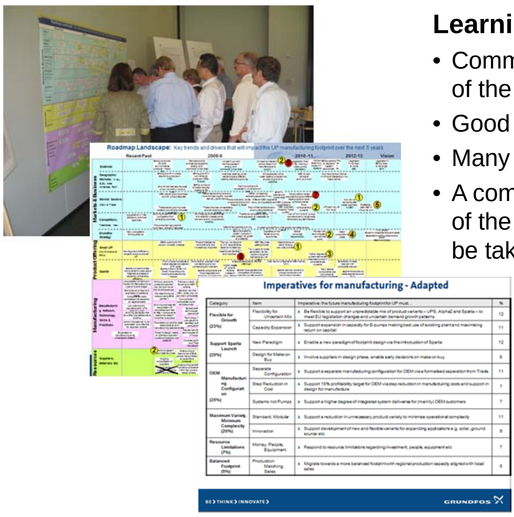


Overall Learning points

- Involvement and engaging of all stakeholders
- Valuable debates and commitment
- The process does NOT take the decisions for you

Why?

The landscaping and identification of imperatives

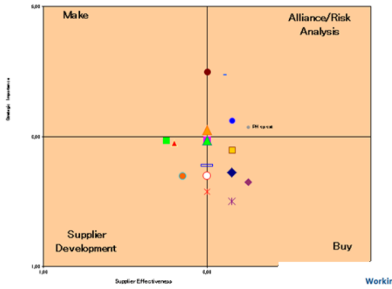


Learning points

- Common understanding of the complexity of the business.
- Good basis for discussions and debates
- Many unanswered questions
- A common understanding and ownership of the direction and decisions needed to be taken

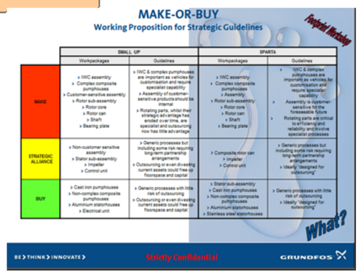
What?

UP Program

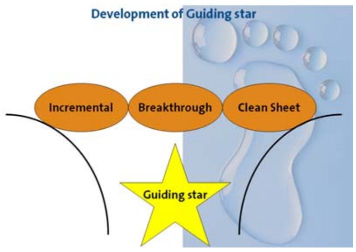


Learning Points

- Need to be sharp on strategic importance →additional work with Technology Management
- The supplier base needed to be known and understood

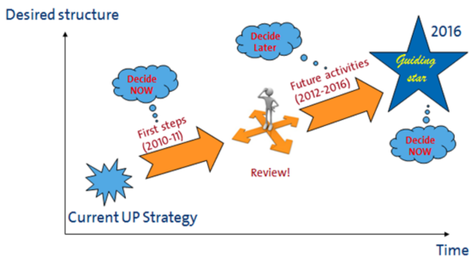


Where?

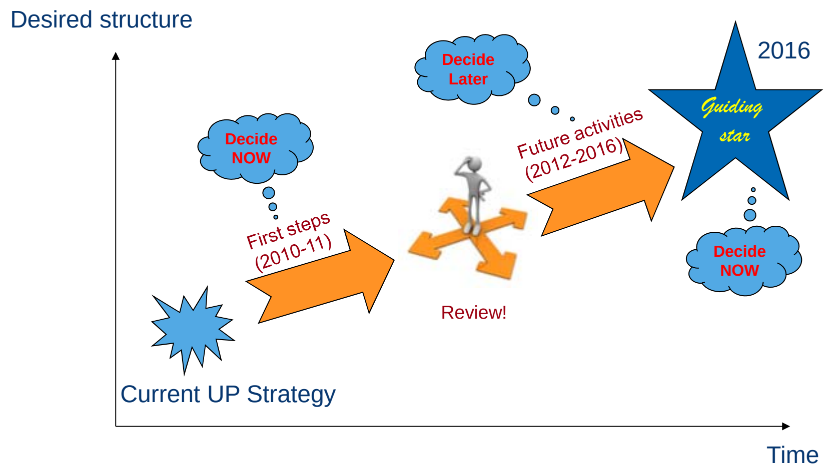


Learning points

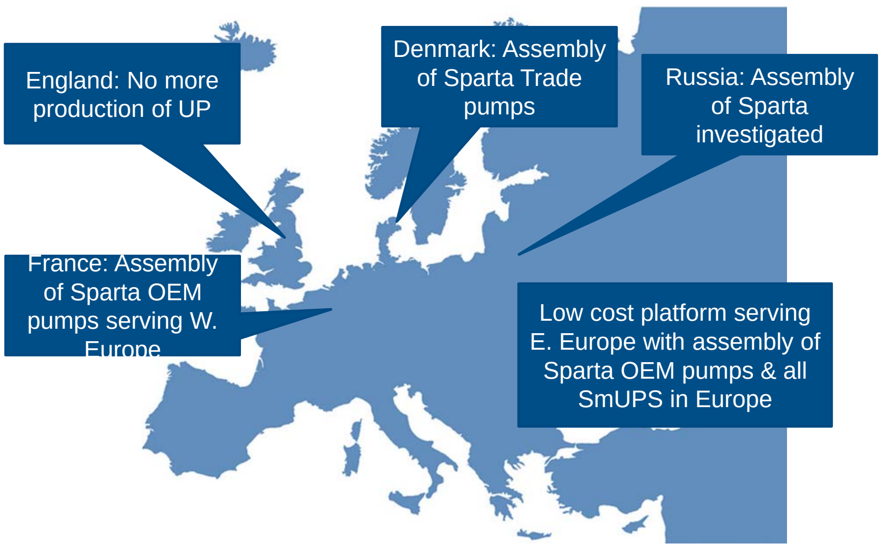
- Difficult as political agenda had to be taken into account
- Outcome not a fixed solution
  - ➢ guiding star



Grundfos Guiding star



Europe – Strategy

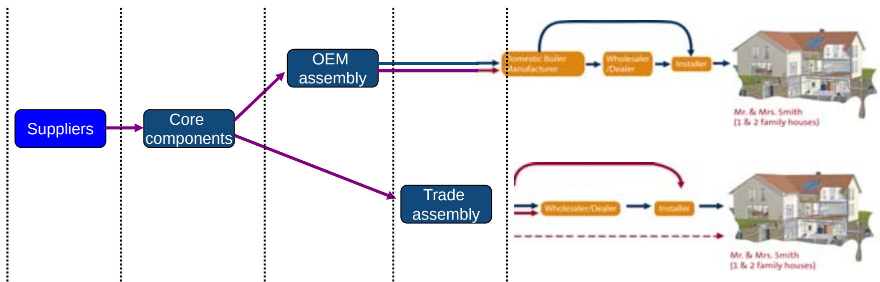


North America – Strategy

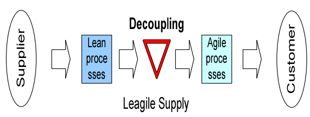
China – Strategy

Where? Future Global Footprint – UP?

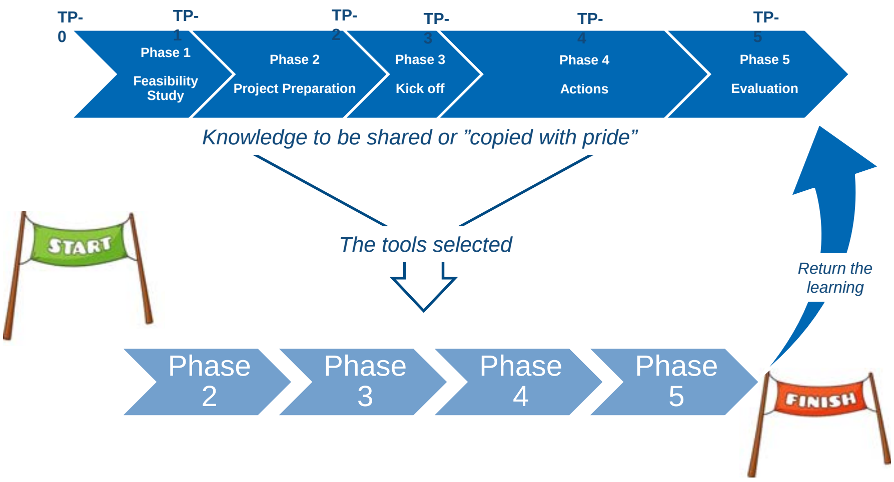
UP Supply Chain concept



	Non-core	Core components	OEM focus	Trade focus
Key words		Lean	Flexibility	Flexibility
		Operational Excellence	On time	Lead-time
		Economy of scale	PPM	
			Partnership/development	
Components	Pump house, stator house, impeller, control unit	Rotor, rotor can, bearing plate, complex composite, stator	Pumps, IWCs	Pumps



How? - The Grundfos Transfer process



New UP Platform

Site selection

New low cost platform to be establish

Dec 2012: Handover

Feb 2012: Contract for construction

2011: First production line transferred

2010: Restart in smaller scale

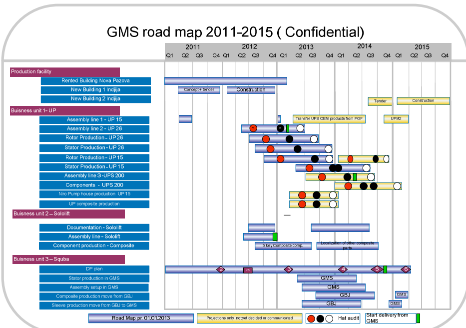
2009: Financial crisis

2008: Search for right location →Feasibility Study

Grundfos Srbija Product roadmap

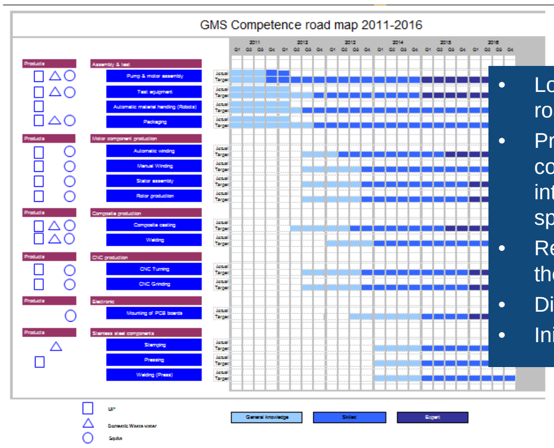
Purpose of plant: Circulators outside EU and low cost platform

- Long term plan from day one, linked to overall footprint in Europe.
- Frequent review and updates of plan based on market development
- Focus to reduce supply chain and get close to market
- Ensure momentum in ramp up in the factory



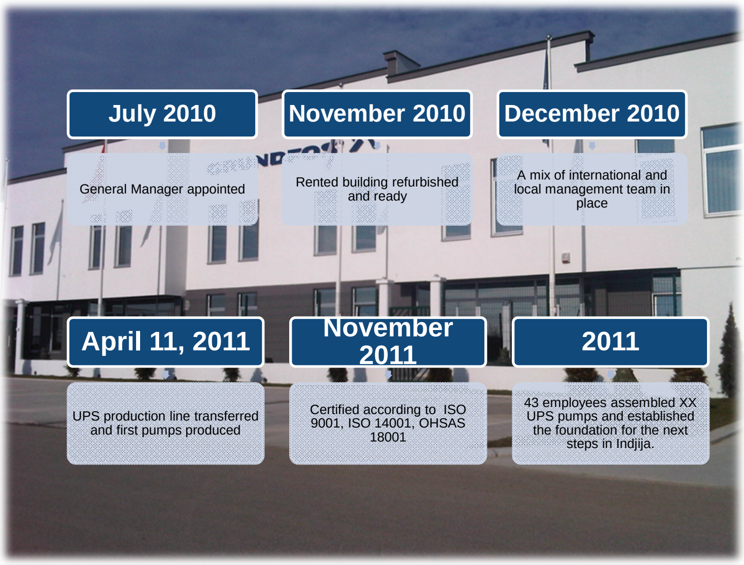
Competence roadmap

Pro active planning of needed competences



- Long term plan to support the product roadmap
- Preparing the organization to ensure competences are available to introduce new product lines at high speed
- Recruitment planning and scouting for the right competences
- Dialogue with local learning institutes
- Initiating training of local talents

The start up

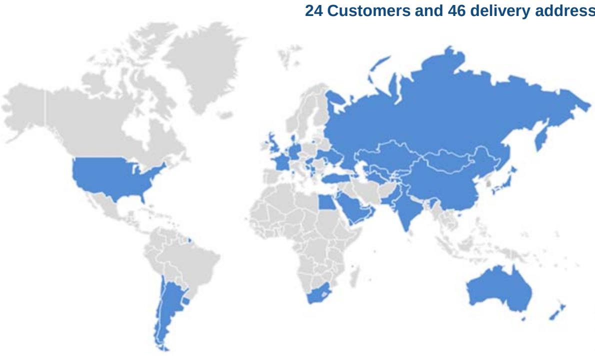


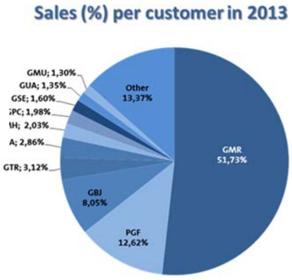
Grundfos Srbija – Indjija

Layout – GMS 1 Indjija

Customer Map

24 Customers and 46 delivery addresses

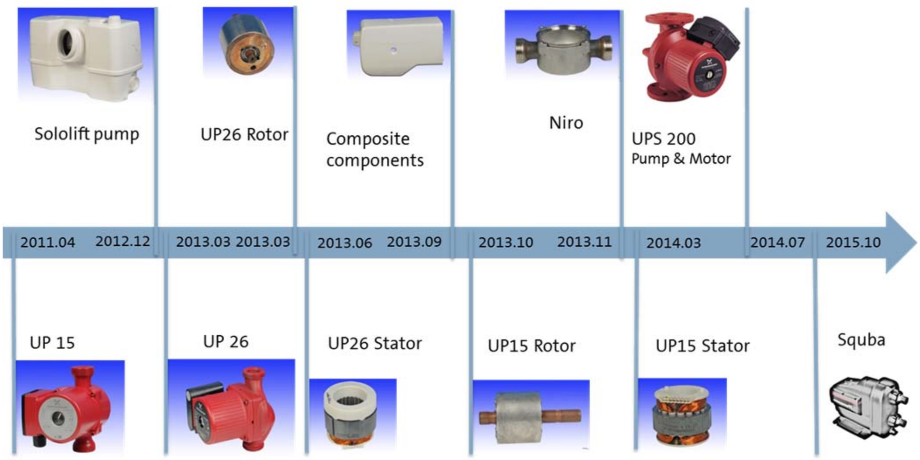




Supplier Map

- Austria
- Belgium
- China
- Czech Republic
- Denmark
- France
- Germany
- Great Britain
- Italy
- Romania
- Serbia
- Slovakia
- Slovenia
- Sweden
- Switzerland
- Taiwan
- Thailand
- Turkey

Grundfos Srbija Product Milestones



Headcount Development in Grundfos Srbija

FOCUSED ON PEOPLE

2011 43

2012 103

2013 238

2014 367

be think innovate

GRUNDFOS

Sales Development in Grundfos Srbija

RELENTLESSLY AMBITIOUS

2011 19 €

2012 47 €

2013 56 €

2014 92 €

*million Euro

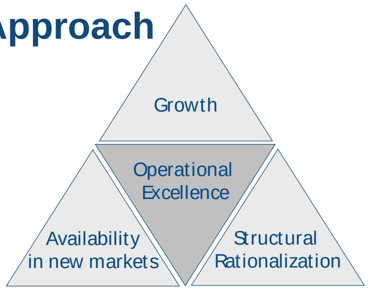
be think innovate

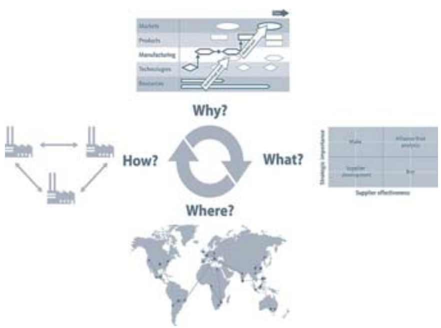
GRUNDFOS

Investments in Grundfos Srbija

***million Euro**

Our Approach





Thank you for your attention

ⓔCOMMERCE

IfM Centre for International Manufacturing | UNIVERSITY OF CAMBRIDGE

18th Cambridge International Manufacturing Symposium

Unilever

eCommerce - Changing shopper habits and the impact on international manufacturing

Dhivant Patel
Global eCommerce Supply Chain Manager
Unilever, Group Customer Service Excellence

IfM MANAGEMENT TECHNOLOGY POLICY

ⓔCOMMERCE

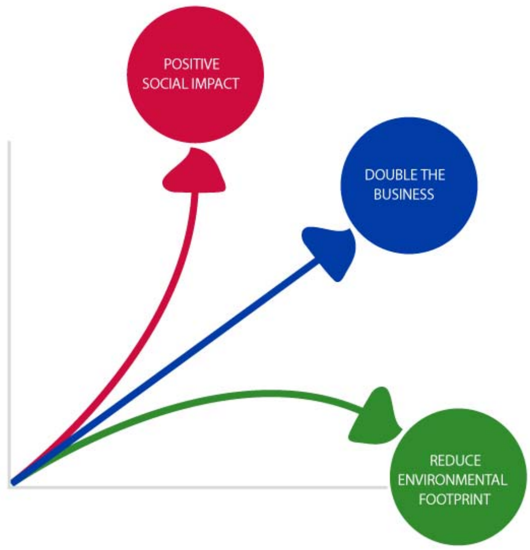
DHIVANT PATEL

Unilever

amazon

IfM MANAGEMENT TECHNOLOGY POLICY

OUR COMPASS STRATEGY



Our vision is to double the size of the business, whilst reducing our environmental footprint and increasing our positive social impact.

The Compass provides a blueprint for success by identifying what we must do to win share and grow volume in every category and country.

FAST FACTS - 2013

EMERGING MARKETS NOW REPRESENT

57%

OF TURNOVER

190

COUNTRIES IN WHICH OUR PRODUCTS ARE SOLD

TURNOVER OF **€49.8 BILLION**

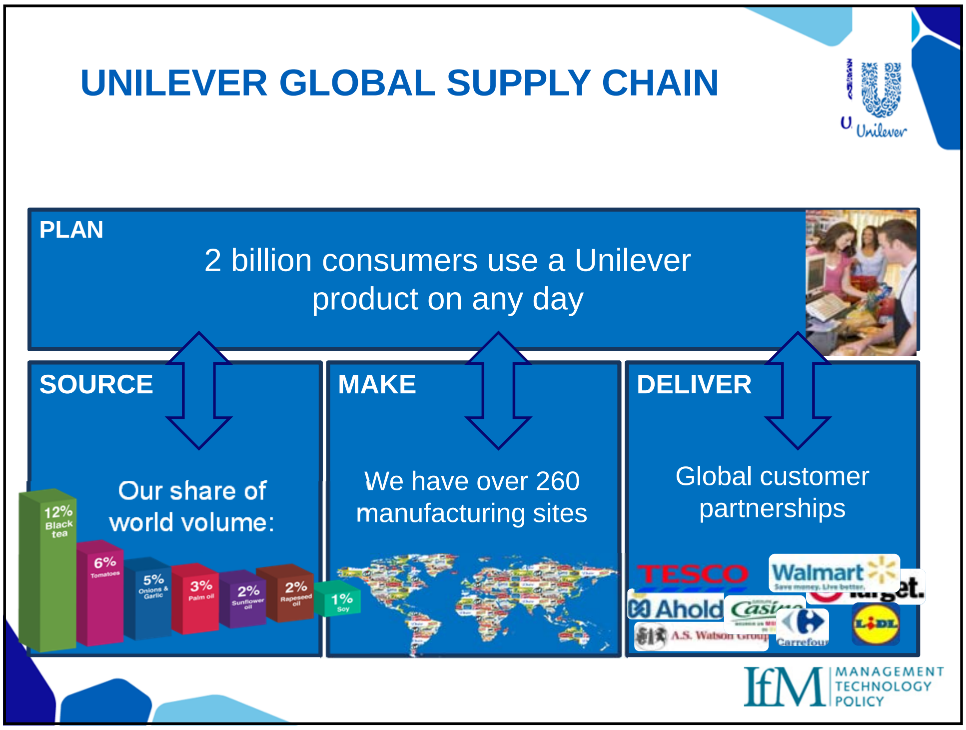
…T END OF 2013

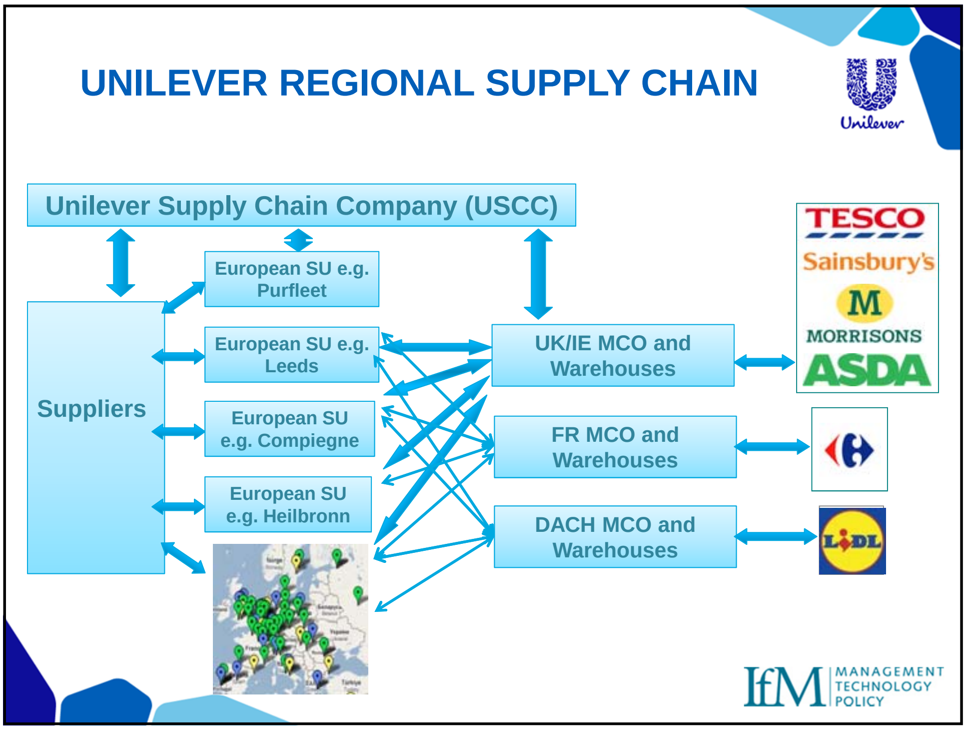
174,000

EMPLOYEES AT THE END OF THE YEAR

€1 BILLION

INVESTED IN R&D WORLDWIDE


UNILEVER GLOBAL SUPPLY CHAIN
Unilever
PLAN
2 billion consumers use a Unilever product on any day
SOURCE
Our share of world volume:
12% Black tea
6% Tomatoes
5% Onions & Garlic
3% Palm oil
2% Sunflower oil
2% Rapeseed oil
1% Soy
MAKE
We have over 260 manufacturing sites
DELIVER
Global customer partnerships
TESCO
Walmart
Ahold
Casino
A.S. Watson Group
Carrefour
LIDL
IfM MANAGEMENT TECHNOLOGY POLICY


UNILEVER REGIONAL SUPPLY CHAIN
Unilever
Unilever Supply Chain Company (USCC)
Suppliers
European SU e.g. Purfleet
European SU e.g. Leeds
European SU e.g. Compiegne
European SU e.g. Heilbronn
UK/IE MCO and Warehouses
FR MCO and Warehouses
DACH MCO and Warehouses
TESCO
Sainsbury's
MORRISONS
ASDA
LIDL
IfM MANAGEMENT TECHNOLOGY POLICY

METRICS AND END TO END SUPPLY CHAIN

FIRST CHALLENGE – LAST MILE

Over the years we have optimised our consumer and distribution packaging for flow from our factories, through distribution centres and onto shop shelves.

The last step in the eCommerce supply chain presents additional challenges that are as much our concern as they are for retailers.

Let's take a look at a couple of clips to give you a sense of this new last mile....

https://www.youtube.com/watch?v=Aq_jkUVgrc0

http://www.youtube.com/watch?v=rh9n08ecS4Y

CHALLENGE OR OPPORTUNITY?

don't recycle.
refill.
easy as 1,2,3

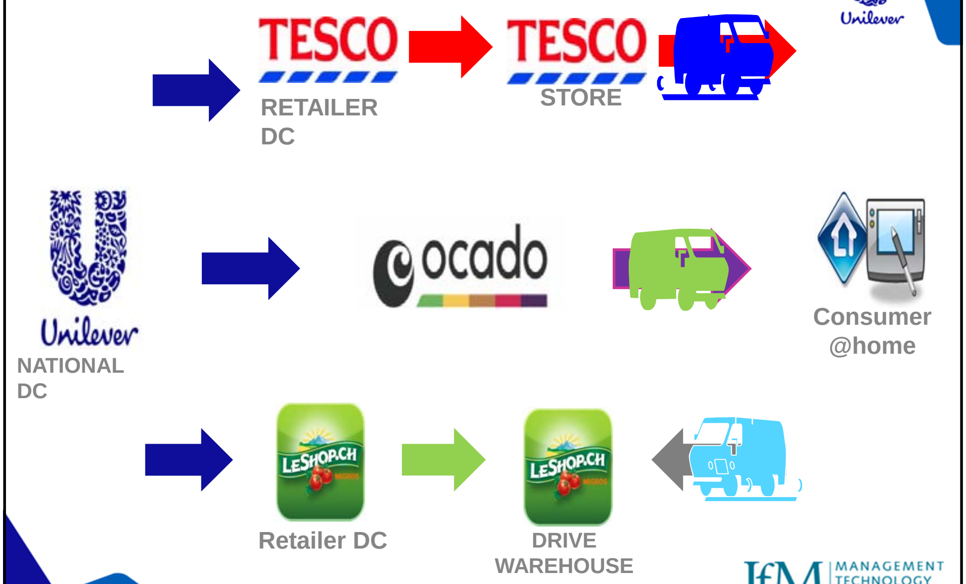
SECOND CONSIDERATION – PICKING

Let's take a look at a couple more clips to give you a sense of the future....

https://www.youtube.com/watch?v=6KRjuuEVEZs

https://www.youtube.com/watch?v=mJ9DPnfDCE8

SECOND CONSIDERATION – DELIVERY



HOW TO IMPROVE THE OPERATING MODEL

THIRD TREND– PERSONALISATION

ULTRA INFORMED

Making smarter choices
Demanding better value
More information than they could ever use or consume!

PERSONALISATION

A 'for me' experience
A 'for me' offers/promotions/deals
A 'for me' assortment

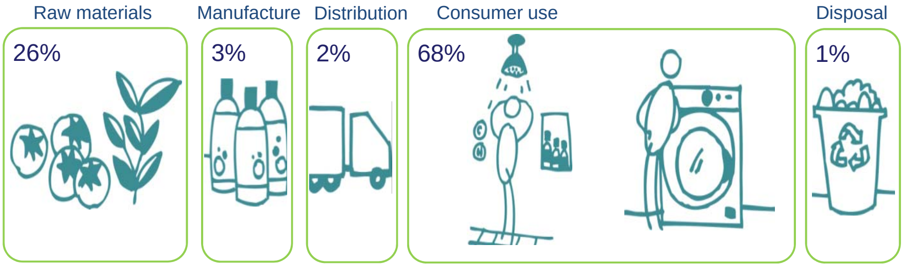
OMNI CHANNEL
(ROPA)

Always on
Anywhere
Anytime
Any Device

OFFER RANGE

ECOMMERCE AND SUSTAINABILITY

Unilever's Global Greenhouse Gas Footprint – 400 million Tonnes CO2e



COMPLEXITY DESTROYING VALUE?

"Companies can tend to get comfortable doing what they've always done with a few minor tweaks. But incremental improvement is guaranteed to be obsolete over time. That is why we are investing in what appear to be speculative products today such as self-driving cars."
- Larry Page

eCOMMERCE

IfM Centre for International Manufacturing

UNIVERSITY OF CAMBRIDGE

18th Cambridge International Manufacturing Symposium

Unilever

QUESTIONS?

Dhivant Patel
Global eCommerce Supply Chain Manager
Unilever, Group Customer Service Excellence

IfM MANAGEMENT TECHNOLOGY POLICY

TATA CONSULTANCY SERVICES
Experience certainty.

A VISION FOR FUTURE MANUFACTURING ENTERPRISES

Jeffrey D. Tew, Ph.D.
Chief Scientist, TCS Cincinnati Lab

Outline

- About Tata and TCS
- Why Should Manufacturing Become Customer-centric
- Innovative Solutions with Digital Reimagination
- Digital Footprint Visualization
- Plant-in-Box
- Enterprise Dashboards
- The Global Connected Machine
- The Digital Customer in Collaboration
- Towards a Customer-Centric Organization

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Tata Group

India's largest conglomerate

100 operating companies in 7 business sectors

Information Technology & Communication	Engineering	Materials	Services	Energy	Consumer Products	Chemicals

TCS at-a-glance

45+ Years in Business

13.4 Billion US$ in FY 14 revenues *

300,000+ Employees *

118 Employee Nationalities *

1000+ Clients in

46 Countries where TCS has presence

** **Source :***
Figures from TCS Analyst Report FY Q2-14
*Employee count includes **285,250** employees in subsidiaries*

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Manufacturing is Continuously Transforming

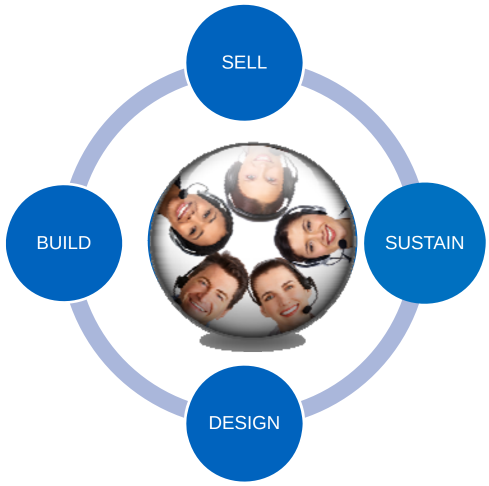
- New technologies arrive at an ever faster pace
  - Big Data, Cloud, Virtualization, Internet of Things,, …
  - Tablets, iPhones, Human Machine Interface, Natural User Interfaces,
- Customers expectations continue to increase
  - Greater product variety with features and functions
  - Personalized Just-in-time configurability
- Manufacturing enterprises are racing against
  - Diminishing product development time
  - Continuing global competitive pressures
- Business models shifting
  - Made to Stock towards Engineer to Order or Configure to Order

Today the customer expects

- Best products – innovative design
- Flawless quality – no mistakes, no errors
- Responsive features -- greater complexity
- Life cycle relationship – take care of me

Expectations continue to multiply and grow

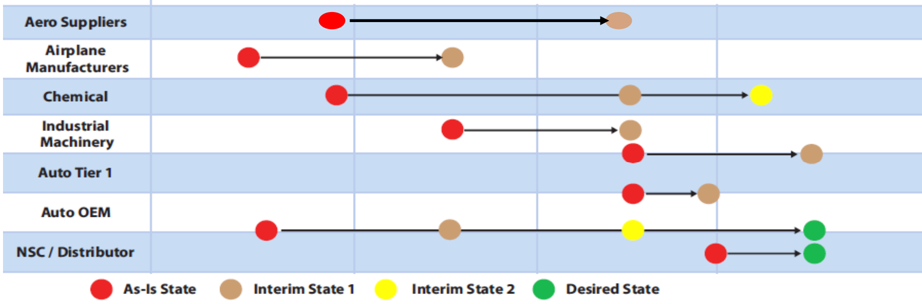
Consequently, Enterprises are Trying to Become Customer-Centric



Enterprises want more of a customer's market share

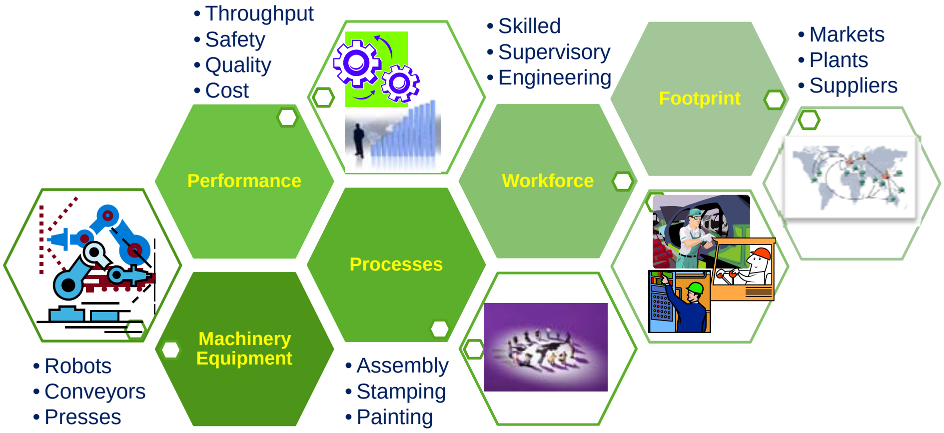
The Industry Center of Gravity is Shifting

	Engineering Oriented	Operations Oriented	Collaboration Oriented	Customer Oriented
	Defining Characteristics			
Focal Point	Engineering	Manufacturing	Supply Chain	Customer Experience
Typical Drivers	Product Focused	Cost Focused	Agility Focused	Service Focused
	New Product Innovation and Lifecycle Processes	Manufacturing Excellence	LEAN Operations	Customer Loyalty
	Cost to Market	Compliance	Scalability	Voice of Customer
Industry	How the industry 'Center of Gravity' is shifting			



Business models are becoming more customer oriented

The DNA of a Manufacturing Enterprise



How do we drive the customer-centric evolution?

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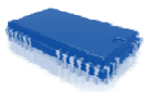
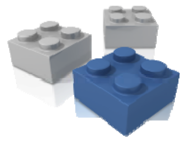
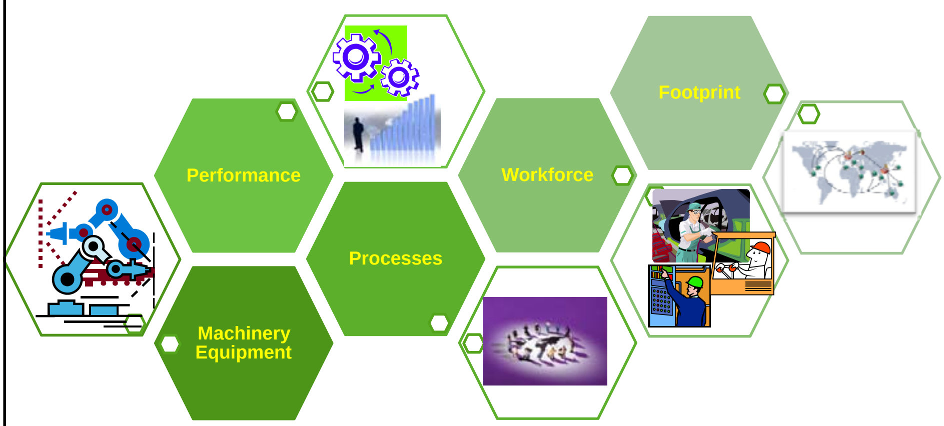
Innovation is Critical to Addressing These Trends

End Customer	Virtualization	New Technology	Standardization	Collaboration
Consumer-ization of manufacturing	Virtualization across product development & Manufacturing	Increasing Embedded Software & Electronics	Complexity reduction	Connected Supply Chain
Made to Order or Configure to Order	Visualization of customer interfaces	Customer driven platforms	Smaller modular factories closer to demand	Collaborate internally, and with Customer
				

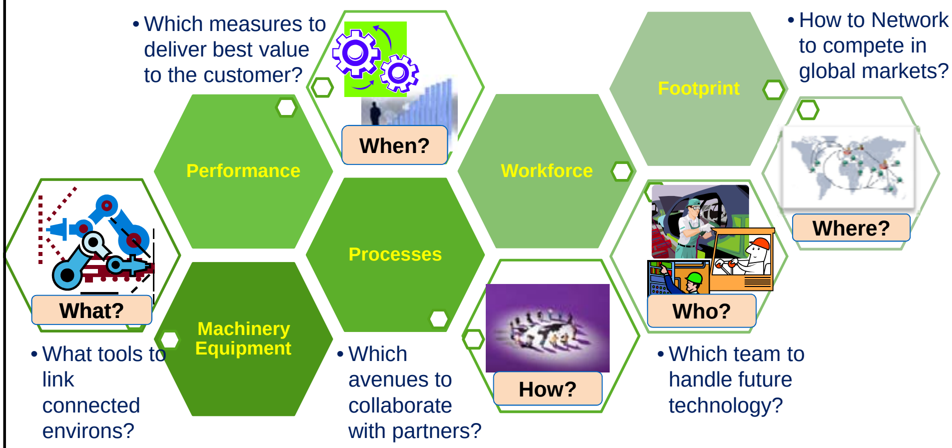
Digital reimagination will result in innovate solutions

Reimagining Digitally the DNA of the Enterprise



The same elements, "digitized", can bring the customer to the center!

Five Key Question can Drive the Reimagination

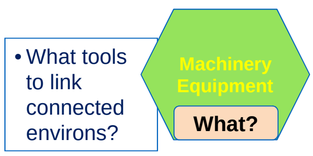


The key is to answer these questions while keeping the focus on the customer!

Synchronous Global Plants

- Share Processes Globally
- Meet Needs Locally
- Synchronize Plants Globally

- Opportunities
  - Balance flexibility with throughput across all plants
  - Capture local needs systematically
  - Single view of plant systems



Link plants across the globe to act as “one”.

Digital Customer in Collaboration

- Allow Customers Configure
- New Features on Demand
- Balance the Enterprise Value

- Opportunities
  - Be customer-centric
  - Ride the wave
  - Enhance service offerings

- Which measures to deliver best value for the customer?

Performance

When?

Use the power of digital to engage the customer in collaboration (actively and passively).

Create the Responsive and Agile Enterprise

- Work with Internal Partners
- Collaborate with Suppliers and other Partners.
- Seamless Transparency!

- Opportunities
  - Validate processes early and often
  - Align and balance processes with stakeholders
  - Balance cost and quality with demand

- Which avenues to collaborate with partners?

Processes

How?

Utilize digital to enable real-time, “cross enterprise” collaboration of all processes.

Global Connected Machine

- Share Best Work Practices
- Leverage Local Capabilities
- Empower Work Teams

- Opportunities
  - Balance machines and humans
  - Nurture local talents systematically
  - Support the operator

- Which team to handle future technology?

Workforce

Who?

Rethinking the roles of people to effectively run the connected enterprise is critical.

Strategic Manufacturing Footprint

- Make where you sell
- Bring suppliers closer – even in-house
- Think “smaller” plants

- Opportunities
  - Plan and track end-customer demand
  - Rapidly set up plants and plant systems
  - Develop strategic supplier footprint

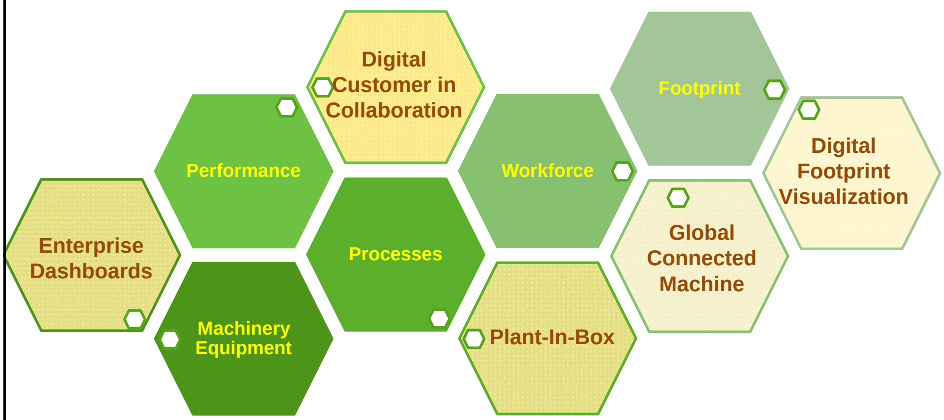
- How to network to compete in global markets?

Footprint

Where?

The digital enterprise allows you to bring plants “closer to customer”

Retooling for Digital Reimagination



Connected Data + Enterprise Analytics + Data Visualization = Value for the Customer

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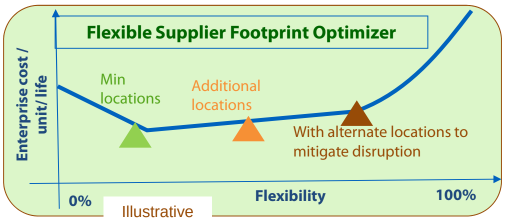
Building a Strategic Supplier Footprint

- Key Questions
  - Future critical technologies?
  - Where to buy capacity?
  - At what cost?
  - How to manage risks?



Need to balance enterprise costs with flexibility using future product data

Digital Footprint Visualization

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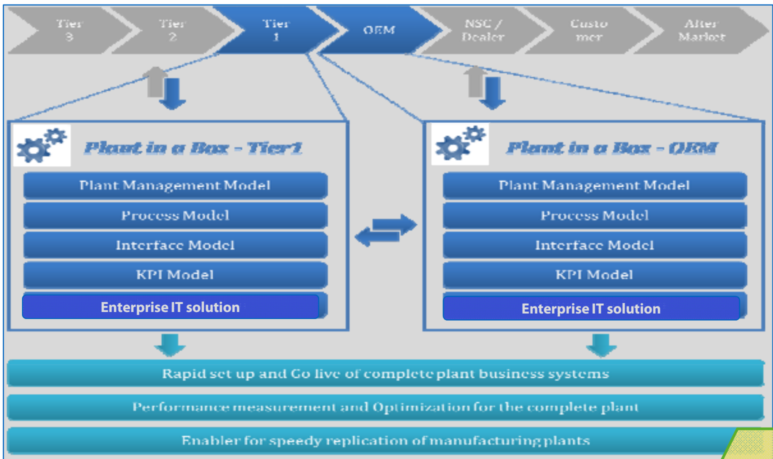
Towards a Global Connected Machine

Need to link
processes and people
through
simple visual data interfaces!

Plant-In-Box

Collaborating Across the Enterprise



All plants aligned with
a single view of truth!

Plant-In-Box

TATA CONSULTANCY SERVICES
Experience certainty.

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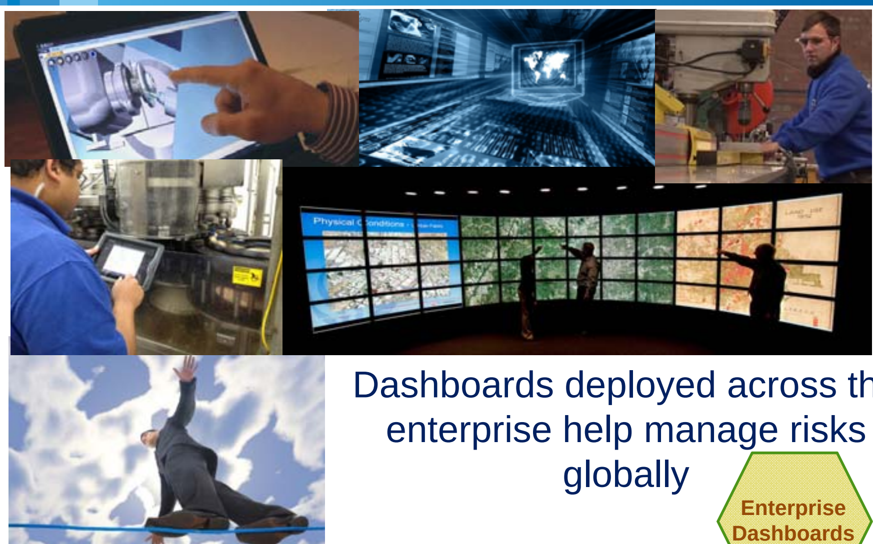
Developing a Responsive Agile Enterprise



Dashboards deployed across the enterprise help manage risks globally

Enterprise Dashboards

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- Innovative Solutions with Digital Reimagination
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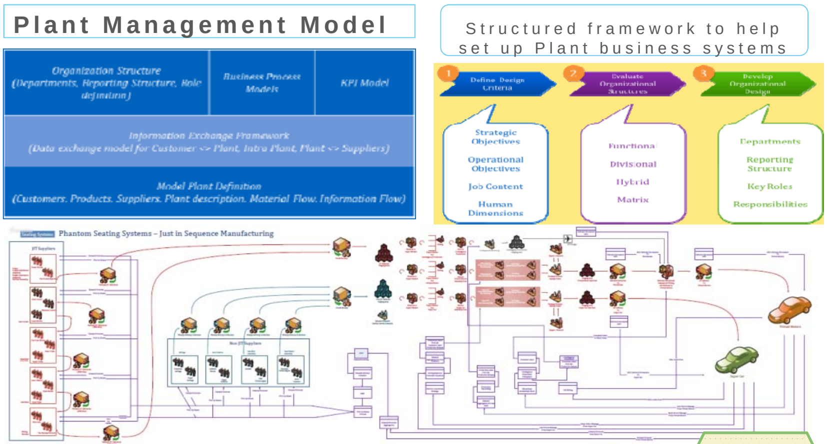
- Plant-in-Box
- Enterprise Dashboards
- The Global Connected Machine
- The Digital Customer in Collaboration
- Towards a Customer-Centric Organization

Deploying Common Platform Rapidly



Common globally while allowing efficient individual strategies!

Global Connected Machine

Outline

- About Tata and TCS
- Why Should Manufacturing becomeCustomer-centric
- Innovative Solutions with Digital Reimagination
- Digital Footprint Visualization
- Plant-in-Box
- Enterprise Dashboards
- The Global Connected Machine
- The Digital Customer in Collaboration
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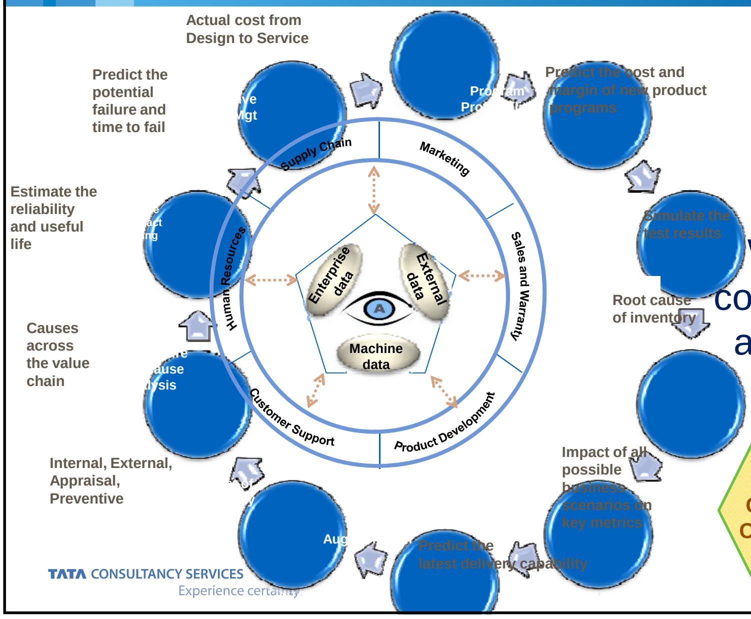
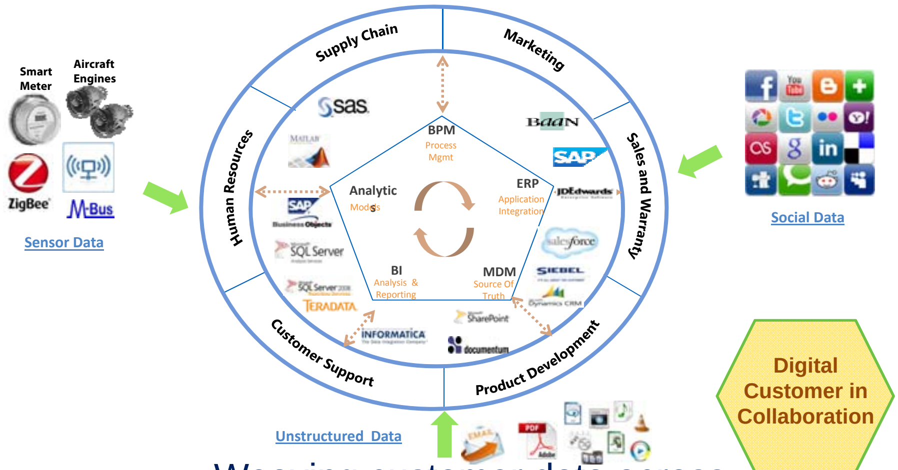
Driving Fact-Based Decisions with Connected Data



Weaving collaboration across the teams

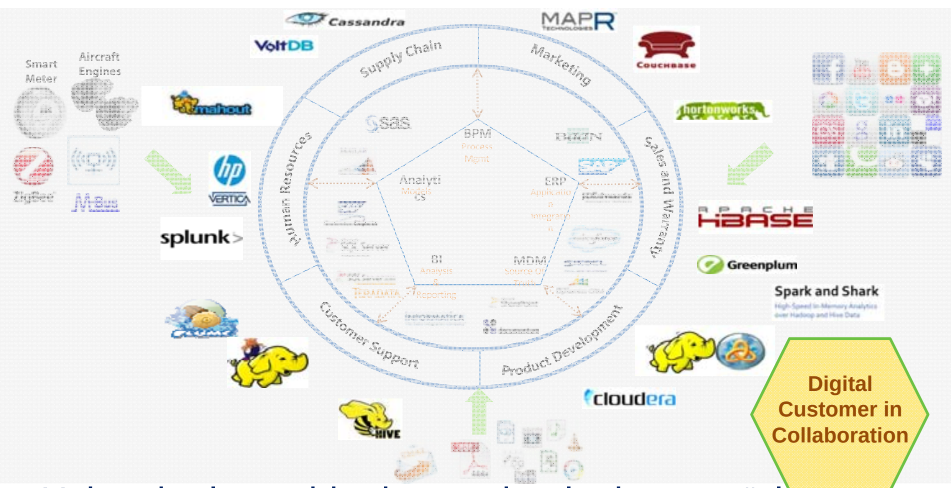
Digital Customer in Collaboration

Linking the Digital Customer into the Enterprise



Weaving customer data across the enterprise enables customer collaboration

Implementing the Customer Feedback Loops



Using the latest big data technologies can "close the loop" with the customer

Outline

- About Tata and TCS
- Why Should Manufacturing becomeCustomer-centric
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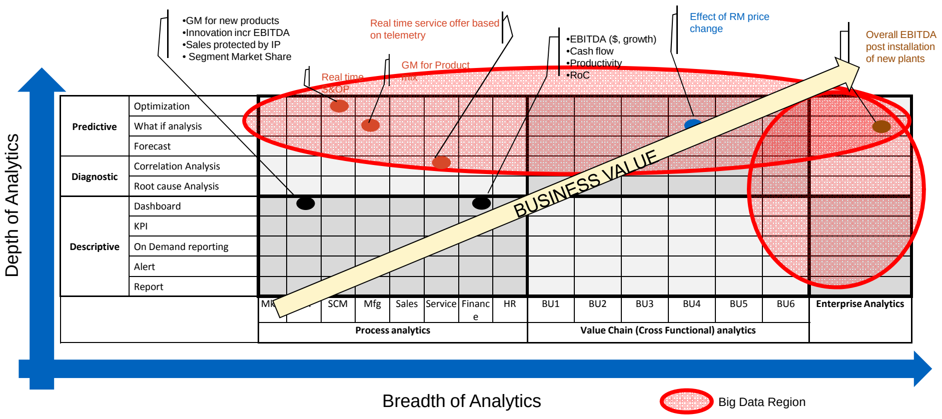
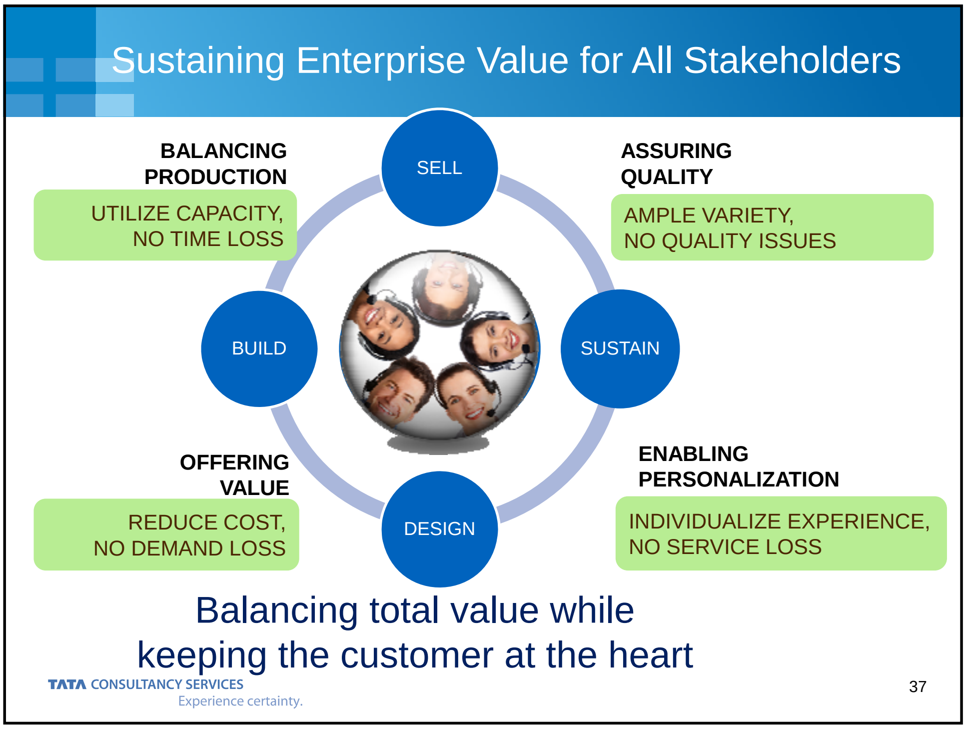
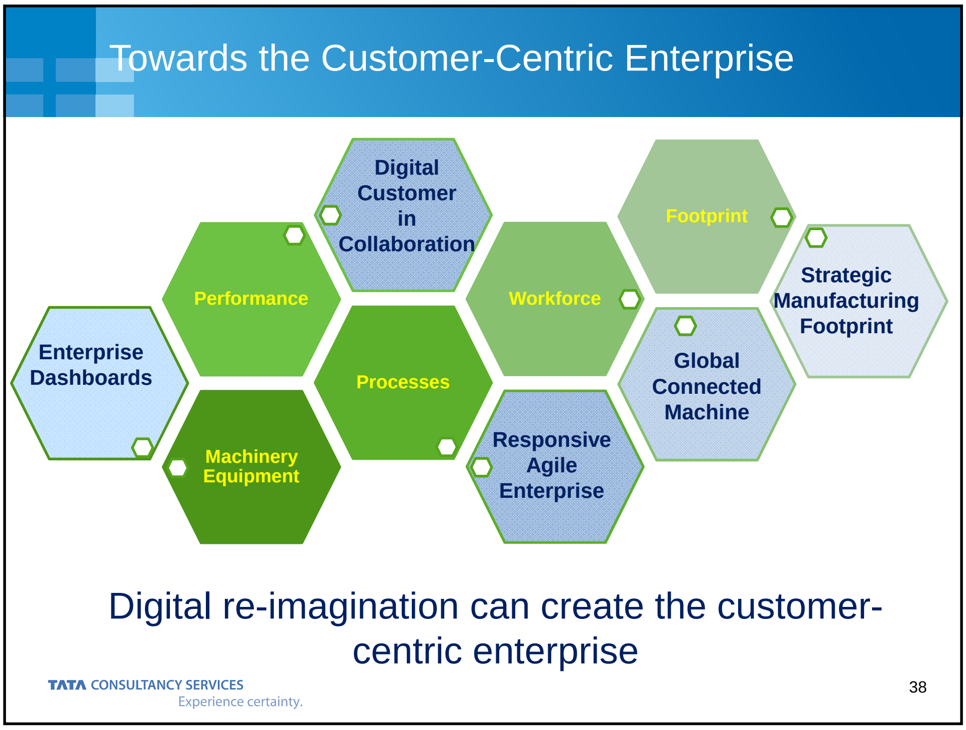
Enhancing the Analytics Spectrum for the Enterprise



Analytics is the key to leveraging fact-based decisions across the enterprise.


Sustaining Enterprise Value for All Stakeholders
BALANCING PRODUCTION
UTILIZE CAPACITY, NO TIME LOSS
SELL
ASSURING QUALITY
AMPLE VARIETY, NO QUALITY ISSUES
BUILD
SUSTAIN
OFFERING VALUE
REDUCE COST, NO DEMAND LOSS
DESIGN
ENABLING PERSONALIZATION
INDIVIDUALIZE EXPERIENCE, NO SERVICE LOSS
Balancing total value while keeping the customer at the heart
TATA CONSULTANCY SERVICES
Experience certainty.
37


Towards the Customer-Centric Enterprise
Digital Customer in Collaboration
Footprint
Performance
Workforce
Strategic Manufacturing Footprint
Enterprise Dashboards
Processes
Global Connected Machine
Machinery Equipment
Responsive Agile Enterprise
Digital re-imagination can create the customer-centric enterprise
TATA CONSULTANCY SERVICES
Experience certainty.
38

TATA CONSULTANCY SERVICES
Experience certainty.

TATA

Thank You

IT Services
Business Solutions
Consulting

squeezing improvements

innocent's outsourced supply chain journey

capturing value from our global supply chain

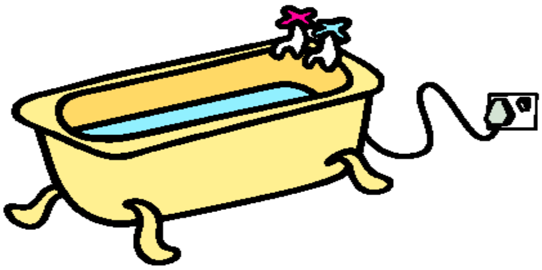
IfM symposium - 11 September 2014

a little introduction

- our supply chain
- the journey so far
- our next steps

15 years ago, an IfM alumnus grabbed his mates…

rejected at least one bad idea…



conducted some extensive consumer research…

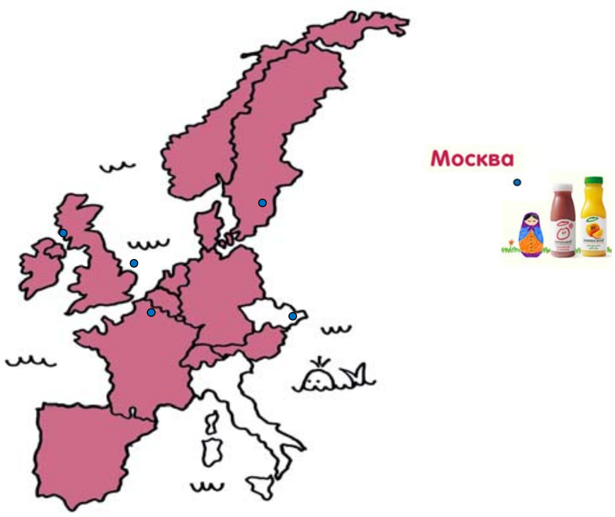
...and found something that does good: easy fruit & veg

2 of your 5 a day

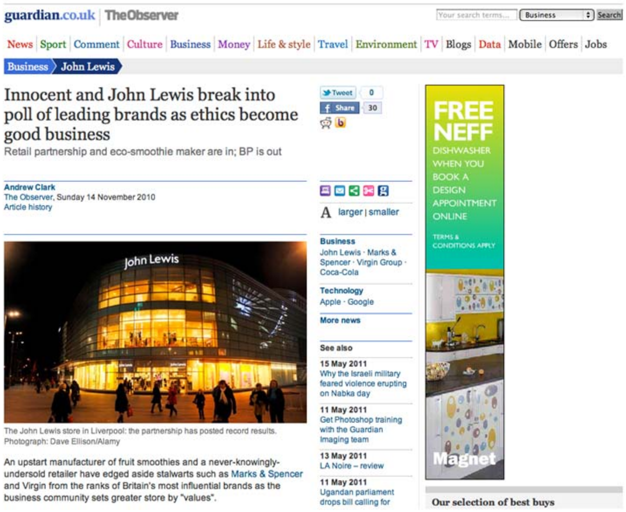
on 29th April 1999 we had 3 SKUs and made our first sale

today it’s more like 200 SKUs and 3 million litres a week

across 16 countries, with 330 employees in 6 offices in Europe & Moscow



one of the UK’s most influential brands



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Business > John Lewis

Innocent and John Lewis break into poll of leading brands as ethics become good business

Retail partnership and eco-smoothie maker are in; BP is out

Andrew Clark
The Observer, Sunday 14 November 2010
Article history

The John Lewis store in Liverpool: the partnership has posted record results. Photograph: Dave Ellison/Alamy

An upstart manufacturer of fruit smoothies and a never-knowingly-undersold retailer have edged aside stalwarts such as Marks & Spencer and Virgin from the ranks of Britain's most influential brands as the business community sets greater store by "values".

Business
John Lewis · Marks & Spencer · Virgin Group · Coca-Cola

Technology
Apple · Google

More news

See also

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Why the Israeli military feared violence erupting on Nabka day

11 May 2011
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13 May 2011
LA Noire – review

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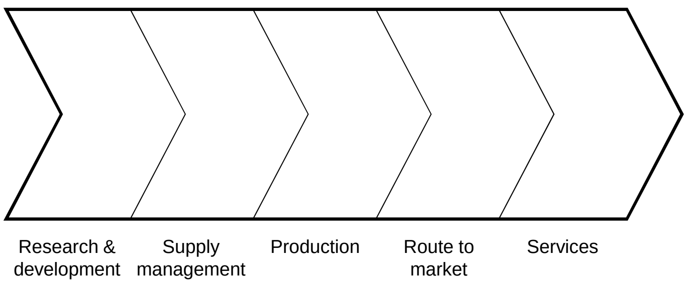
Ugandan parliament drops bill calling for

Our selection of best buys

- a little introduction
- **our supply chain**
- the journey so far
- our next steps

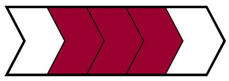
are we a manufacturer – or an integrator – or both?

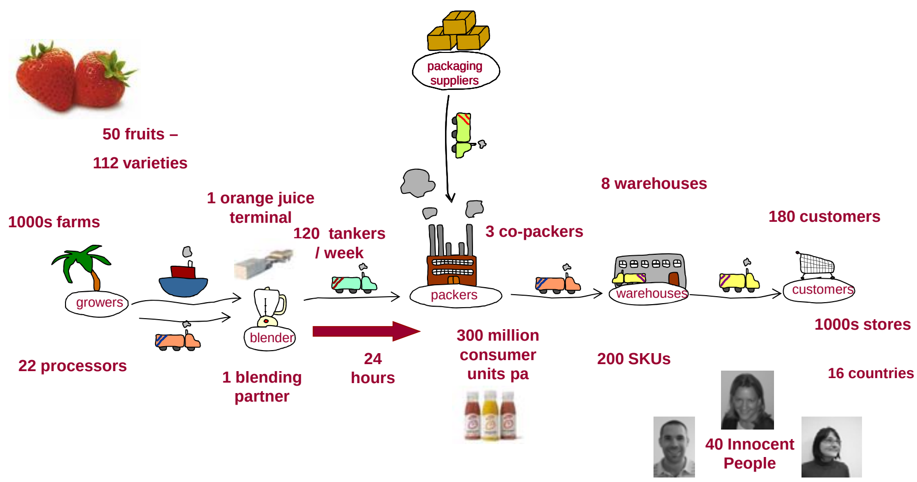
our end-to-end supply chain is entirely outsourced,
but we take a hands-on approach to control it



we usually conduct R&D and provide 'services' in-house
(engaging third parties occasionally)

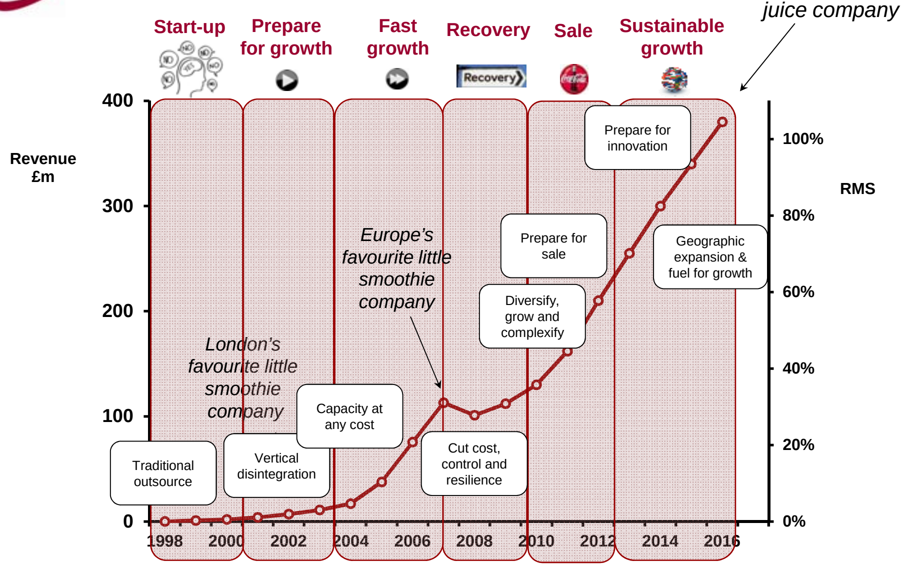
our end-to-end supply chain today:





- a little introduction
- our supply chain
- the journey so far
- our next steps

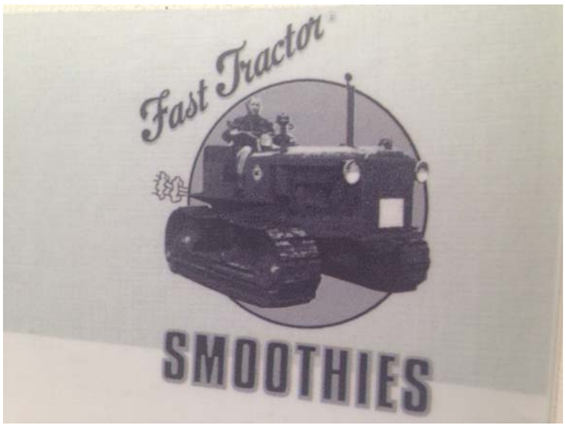
a journey in six phases:



Start-up

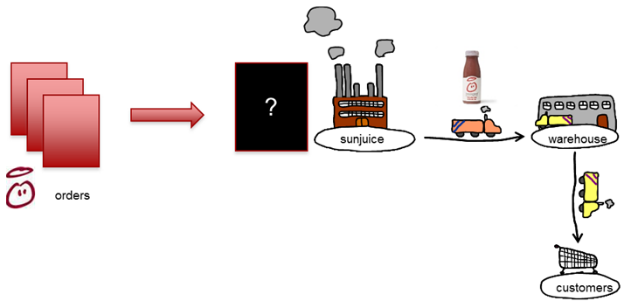
challenge 1: make the product

no concentrates   no preservatives   no colourings   no added sugar



Start-up

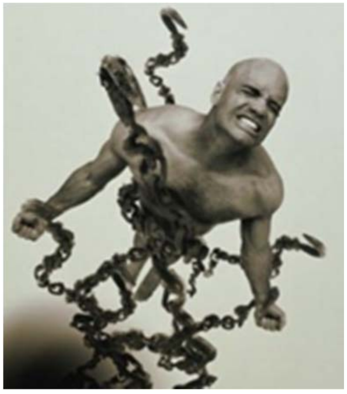
we found our first partner, Sunjuice, who could make this novel product and route to market work



challenge 2: break the growth constraints

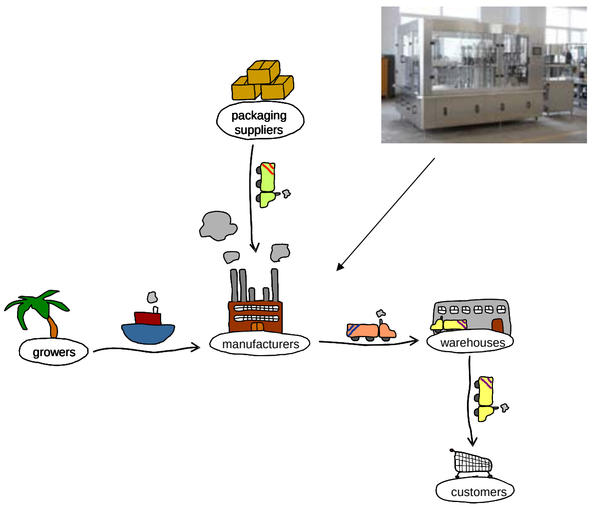
Prepare for growth

- shelf-life
- blending capacity
- take-home formats
- ingredient availability



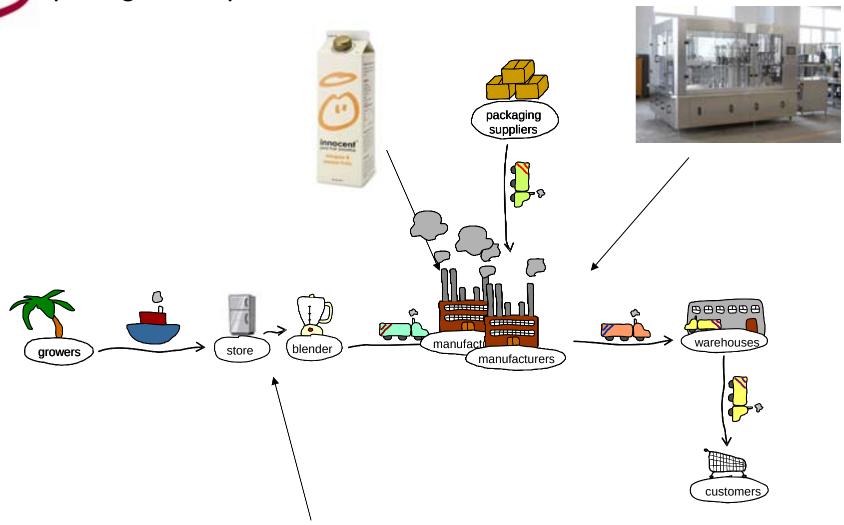
we commissioned a cleaner filler…

Prepare for growth



Prepare for growth

added two partners who knew about scale blending and putting thick liquids in boxes…



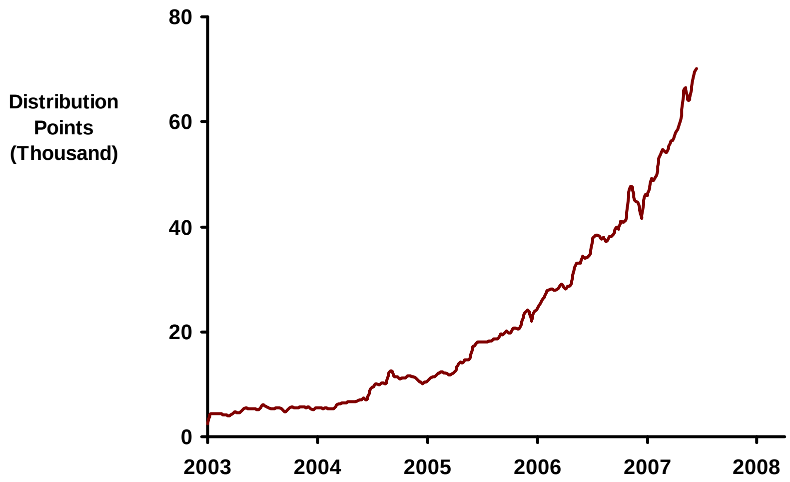
Vertical Dis-integration

Prepare for growth

…and learnt the art of fruit sourcing

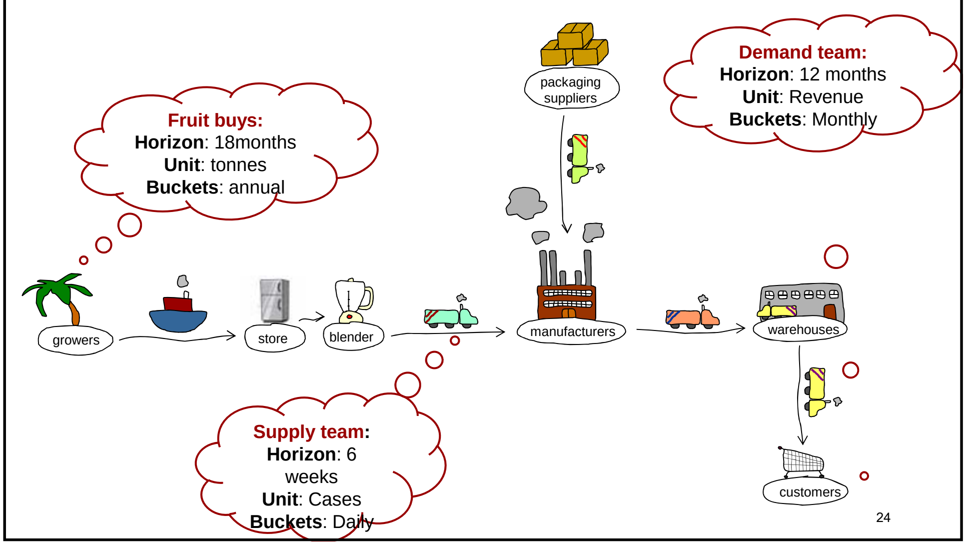
Fast growth

challenge 3: keeping up with demand



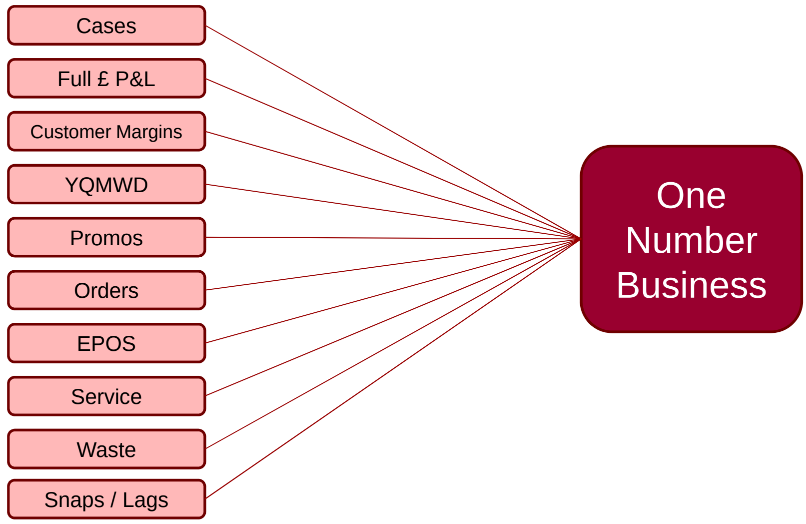
Fast growth

our suppliers scaled up quickly but planning was hard



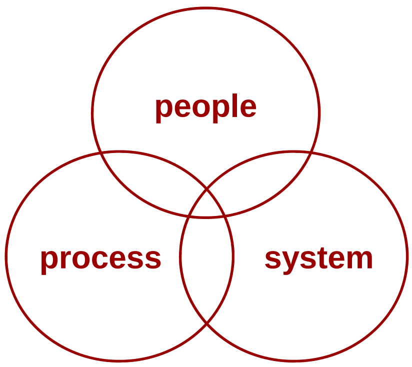
Fast growth

we had to develop joined up forecasting and planning



Fast growth

we think there are 3 pillars of forecasting success



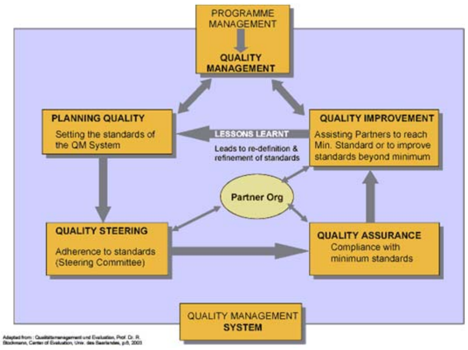
Fast growth

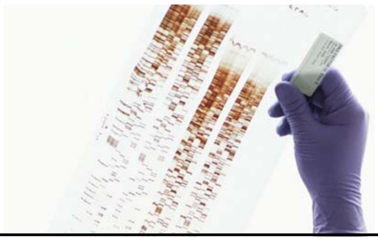
consistency in quality became a problem

Fast growth

so we had to become leading edge in food tech

HACCP

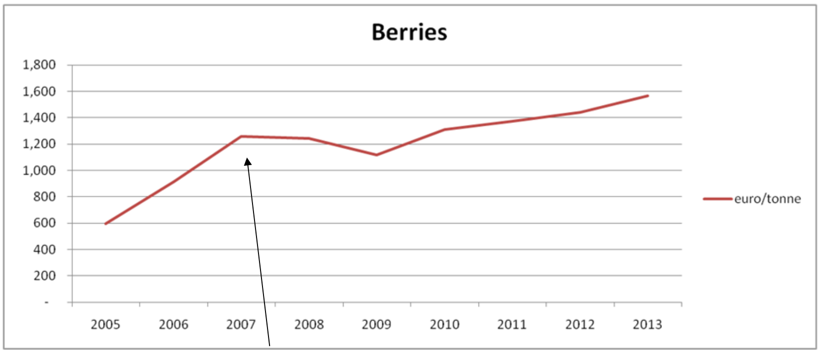




Fast growth

we discovered diseconomies of scale in buying

Cost per tonne – berries



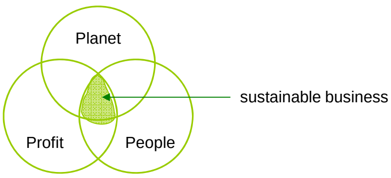
We got too big to keep getting fruit at marginal costs

Fast growth

Adam asked where all the empty bottles go… and we started to take sustainability more seriously…

Leaving things a little bit better than we find them

Balancing the needs of



And focussing on your main impact areas (from farm to fridge and beyond)

Brand	Ingredients	Production	Packaging	Legacy
who we are	*what we use*	*how we make it*	*how we deliver it*	*what we contribute*

running projects to help us and our partners improve

Fast growth

- managing ingredients supply to innocent standards

- investing in agriculture

- working with manufacturers on water waste & energy

- working to continuously reduce our packaging impact

and we established a charitable foundation to share the proceeds of innocent with those who need it

Fast growth

We give 10% of profits to charity each year – the majority of this goes to the innocent foundation.

Since 2004, the foundation has supported sustainable agriculture projects in our sourcing countries or those which rate highly on UN index of need.

In 9 years we have supported 37 projects, committed over £1.5 million to community projects and used our funding to leverage an extra £5.8 million from major public grant givers.

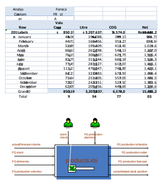
The foundation's projects have so far helped 530,000 people (the equivalent of 100,000 families).

In 2013 the foundation will receive a donation of £2 million from innocent drinks and we will expand our funding programme to support projects addressing world hunger. Watch this space for more information.

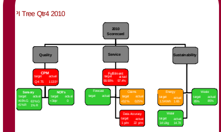
Fast growth

so by 2007 we had an out-sourced model for growth very different from many private labels

sourcing and developing our own ingredients



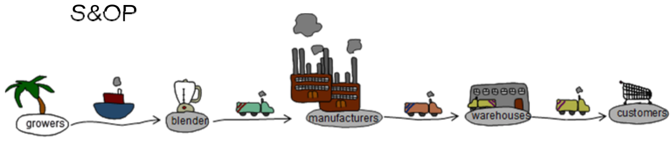
detailed forecasting & production planning – with almost obsessive S&OP



joint performance management and improvement plans including metrics for sustainability

staying at the leading edge of food technology

and vertically dis-integrated



Fast growth

and we had developed some strong partnerships

What we expect…

market leading performance…

network collaboration

commitment to sustainability

What we aim to be …

open and consistent

supportive with expertise

candid

demanding - that helps them stay at the top of their game

Fast growth

but by 2007 our rush for growth had left us fragile and exposed, with some high costs…

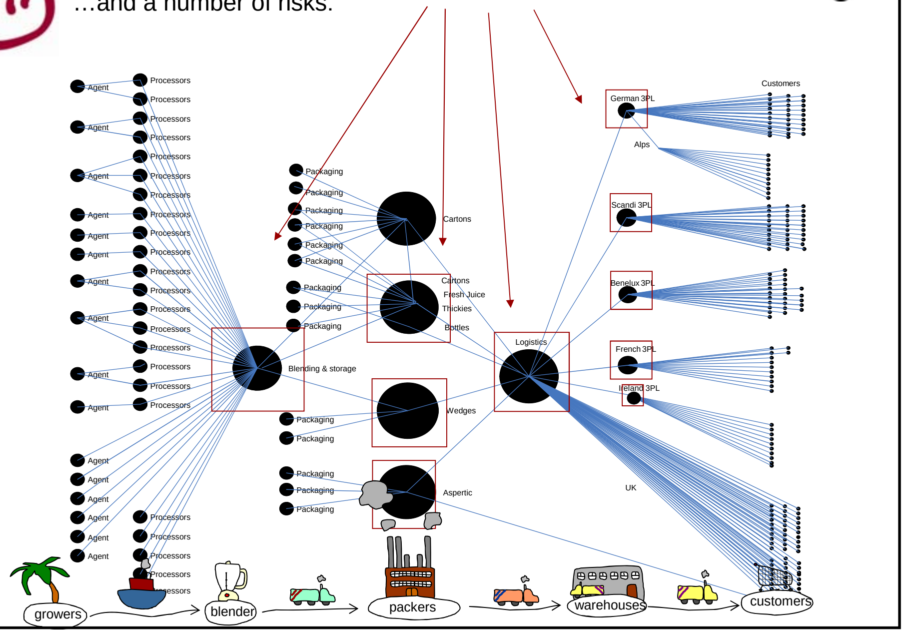
Cost Quality Service Sustainable Lean Robust Agile Flexible

Activity	Cost	Quality	Service	Sustainability	Lean	Resilience	Agility	Flexibility
Sourcing fruit & developing the suppliers								
Fruit Contract planning & mgmt								
Ing forecasting & inventory mgmt								
Ing transport / unit load mgmt								
Ing cost control								
Production planning								
Packaging buying + mgmt								
Blend / pack cost control								
Blend / pack network and supplier mgmt								
Forecasting and S&OP								
Stock control/fulfillment								
UK 3PL mgmt								
Int 3PL mgmt								
LOGS control								
Customer mgmt / service / order mgmt								
Customer supply development								

Fast growth

…and a number of risks:

high exposure points



Fast growth

so we weren't ready for this…

Fast growth

or this…

UK consumer confidence is almost directly correlated with the smoothie market

Source: Daily Telegraph

challenge 4: recovery

It turned out that 2008 was not the easiest time for me to join innocent….

- *Uncertain and dramatically falling demand for smoothies*
- *Pressure to launch new products quickly*
- *Long expensive contracts and commitments for ingredients and services*
- *Pressure to reduce costs to off-set increased commodity prices and FX*
- *Pressure for deeper promotions*
- *Increased risk of insolvency of partners*
- *Changing and uncertain consumer preferences*
- *Potential for increased competition from companies trying to diversify*
- *Growth opportunities in sub-scale new markets*
- *A brand to protect built on a reputation for premium quality and ethical operations*

we developed a resilience strategy - RALF

	Robust	Agile	Lean	Flexible
				
what?	able to withstand disruptions to components	quick and well-coordinated	containing little or no excess	capable of modification or adaptation
why?	reduce fragility	we can exploit opportunities that start small	exploit scale for predictable demand	respond easily to structural changes in demand
how?	operational back up supply for each activity	one facility with flexibility at reasonable cost	the other designed to exploit scale	flexible blend of partners and contracts

Recovery

in production, our RALF contingency network translates into:

Big lean guy…

…a little agile guy…

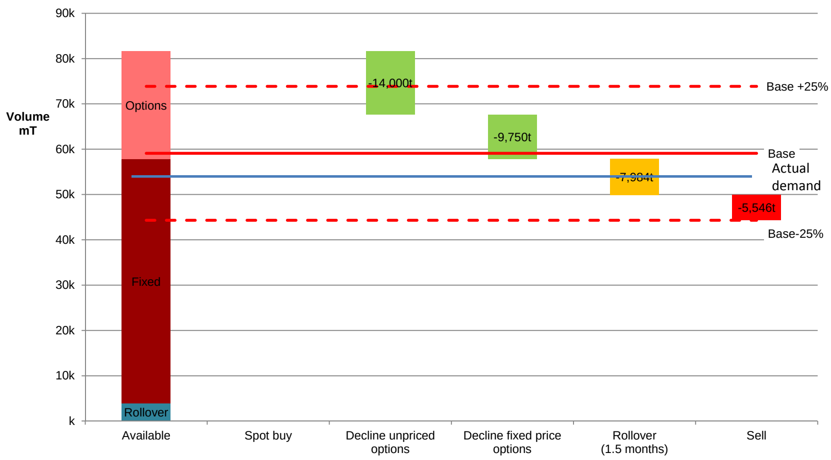
…and someone waiting in the wings

Recovery

in fruit sourcing, it means agreed flex & options

Recovery

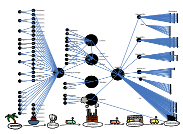
2012 availability damper for apple:



Recovery

we summed up our learning into 5 principles:

out-sourced but in-control	closer to the fruit	**R**esilient **A**gile **L**ean **F**lexible	based on partnerships	sustainable for the long term



and we applied them aid recovery

- match work better to suppliers' strengths
- use a formal set of network roles to build resilience – RALF components
- kaizen recipes to eliminate expensive ingredients not adding value
- leverage long term relationships to trade way out of wrong commitments
- build flexibility into sourcing contracts for agreed cost
- refine S&OP processes to help make sales and supply more collaborative

early steps towards RALF (and a great new partner) saved our necks in late 2008

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Page last updated at 18:31 GMT, Wednesday, 28 January 2009

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Jobs axed at struggling food firm

More than 100 jobs have been lost at a food manufacturer in south Wales which has gone into administration.

Serious Food Ltd in Llantrisant, which employs 420 people, entered into a consultation with 200 employees over a redundancy programme in November.

It is hoped parts of the business will be sold as a going concern

Administrators PricewaterhouseCoopers, which is acting for Serious Food and its subsidiary Sunjuice, has now laid off 127 people with immediate effect.

The company blamed difficult trading conditions in the last 12 to 18 months.

PricewaterhouseCoopers said they are in discussions with a number of

South East Wales
Find out more about what is going on across the region

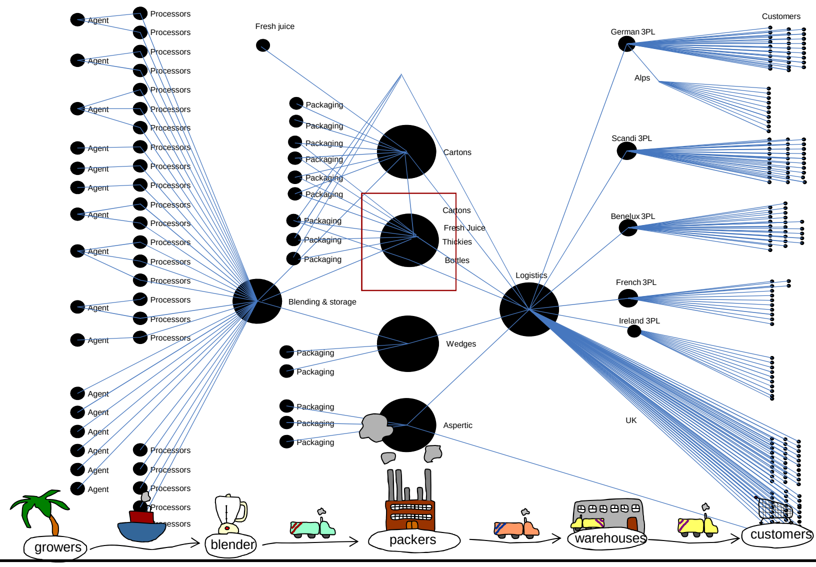
UK RECESSION: WALES

KEY STORIES
- Cash help for car parts factory
- Steel plant restarts production
- 14 jobs go at steel products firm
- New jobs for young people
- Metal plant aid offer is examined

WELSH ECONOMY UPDATE

Recovery

Sunjuice was a “single point of failure” in our supply chain at the time, and a painful lesson

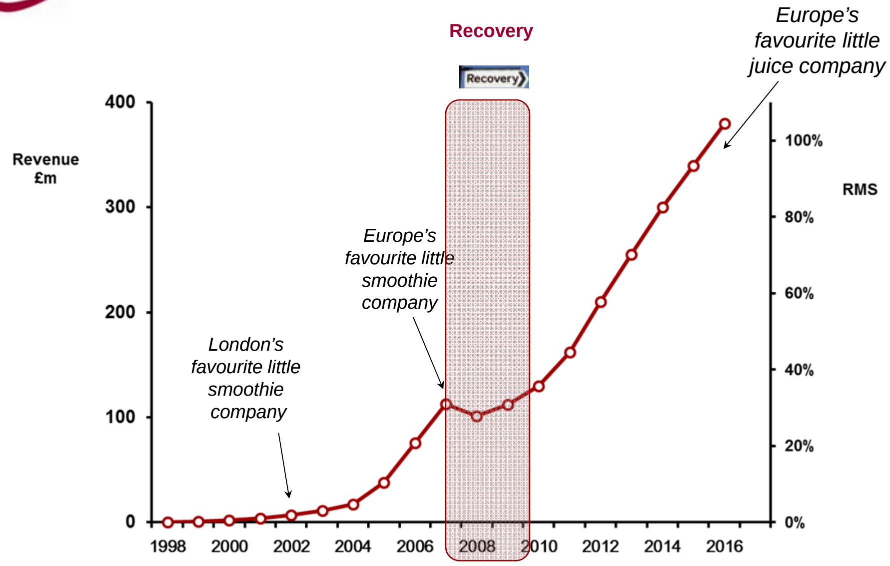


Recovery

RALF in action – our new partner

Recovery

we still had ambitious plans and we needed investment, but the banks were shut



sale preparation

challenge 5: find an investor, enter a new category, double the business, and maximise sales value…

sale preparation

and we found an unexpected perfect partner

sale preparation

so we did a deal with Coca Cola

If you

- Invest £30M in innocent
- Give us Olympic tickets

Then we will

- Double the size of the business
- Restore it to profitability
- Prove the model works
- Get back on the path to Europe’s Favourite Little Juice Company

sale preparation

that enabled us to take the market by storm

sale preparation

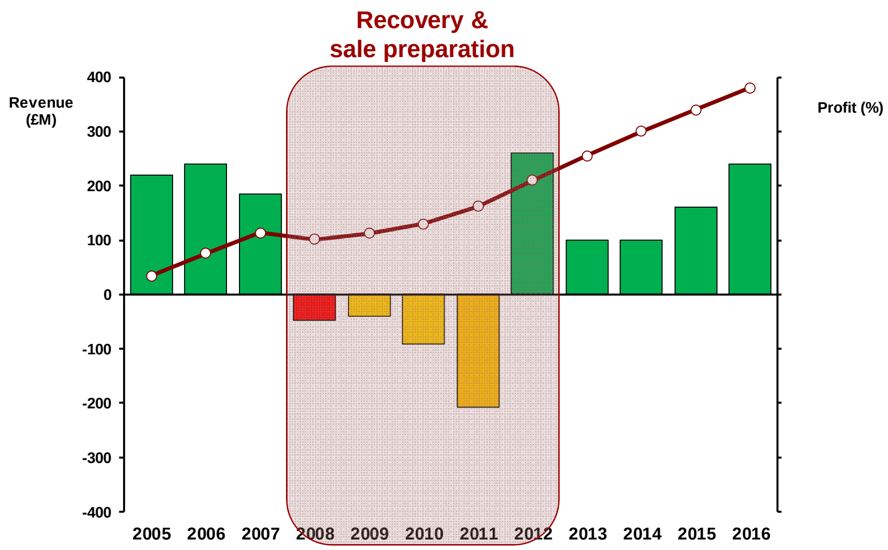
using our RALF network to go from zero to £100m in 2 years…

Agile partner to get to market quickly…

…lean partner to scale up efficiently

sale preparation

Coke’s support enabled us to invest for revenue growth and capacity while buying time to get costs under control



sale preparation

by 2011 we were en route to the perfect strategy

2009	2010	2011	2012	2013
•Urgent cost cutting •£5m challenge •Start RALF for Network and Fruit	•Plan network and RR for 2012 and start delivering. •Deliver innovation. •Deliver quality, cost, service and resilience	• Deliver Innovation •Manage OJ •Complete network changes and RRs • Deliver quality and service at forecast cost	• Operate our simple and robust network – •Flawless operations for minimum cost	• Deliver the next wave of geographical and product growth.

then 2 customers offered the chance to up the stakes

TESCO

Every little helps

sale preparation

we took the challenge and smashed our targets but compromised some of our SC principles

SC state of the nation end 2012:

Cost/Value	Performance	Risk	Energy	Capacity/ Scalability

Volume

120% ★

Service

98%

NPD

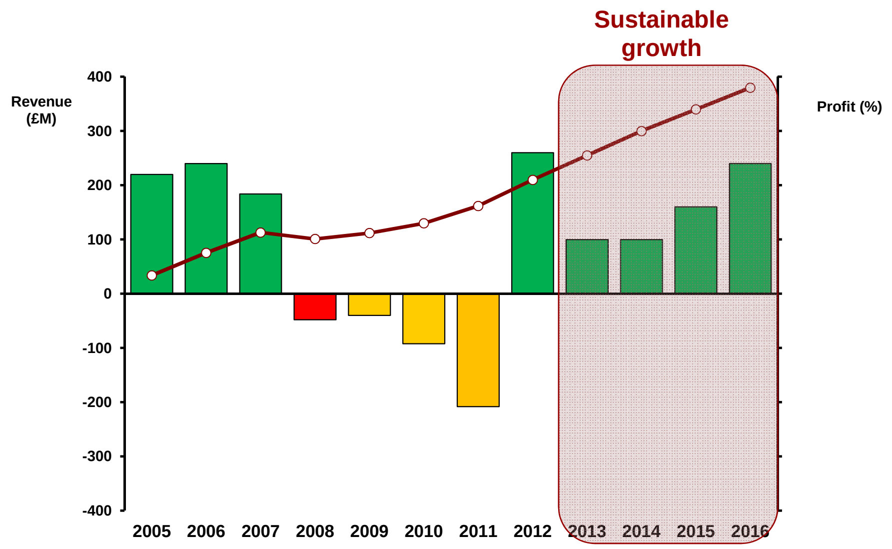
100%

…optimised for the sale but running on empty

- a little introduction
- our supply chain
- the journey so far
- **our next steps**

Sustainable growth

challenge 6: be financially self-sustaining, with growing profit margins over time



what it means for supply…

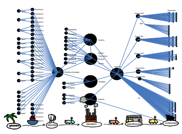
Sustainable growth

- Support geographic expansion
- Security of ingredient supply
- Run as a European group
- Continental production
- Expand innovation pace and enter new technologies
- Manage complexity
- Restore resilience
- Find savings through end to end process improvements

so what about our 5 principles?

Sustainable growth

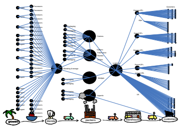
out-sourced but in-control	closer to the fruit	**R**esilient **A**gile **L**ean **F**lexible	based on partnerships	sustainable for the long term



Sustainable growth

the principles remain, but with one addition as we look to develop continuous improvement skills in our unusual supply chain

out-sourced but in-control based on partnerships	closer to the fruit	**R**esilient **A**gile **L**ean **F**lexible	getting better every day	sustainable for the long term



- but don't preclude future in-house
- stay disaggregated to avoid too much 3rd Party control
- a focus on deepening partnerships on key fruits and suppliers

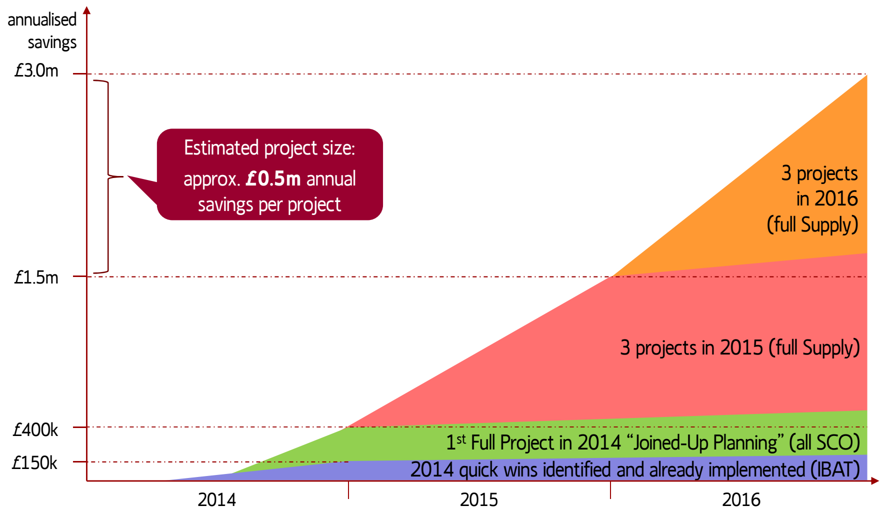
- continue to develop our responsiveness to change of recipes.

- generally no more or less than 2 sites per format, but can be exceptions where appropriate

- always seeking deeper understanding to improve performance

Sustainable growth

and we've set ambitious but realistic cost-saving targets, running projects as part of an "End-to-End" programme looking the whole supply chain



so we are seeking ideas and experience from far and wide - all offers of help welcome

What we already know (tacit knowledge)

What our suppliers already know

Academic research with key partners

Experience of other organisations

THE MANUFACTURING LOCATION DECISION- WHERE'S THE VALUE NOW?

LISA M. ELLRAM, PH.D.

REES DISTINGUISHED PROFESSOR OF SUPPLY CHAIN MANAGEMENT

MIAMI UNIVERSITY- OXFORD OH

AGENDA

- Background
- Journal of Supply Chain Management
- Results from several research projects that inter-relate and are linked to value in global supply chains
- Time for questions

BACKGROUND: THE ORIGINAL MIAMI

- Miami University was founded in *1809, town* of Oxford in 1811
  - named for the Myaamia Indians who previously lived in the area
  - Still have a relationship with them, archiving their history, preserving their language
- Miami Florida was incorporated as a city on July 28, 1896 with a population of just over 300.
  - It was named for the nearby Miami River, itself named for the Mayaimi Indians who previously lived around Lake Okeechobee
  - U of Miami- founded in 1925

THE “REAL” MIAMI UNIVERSITY

JOURNAL OF SUPPLY CHAIN MANAGEMENT

- In our 50th year of publication!!!
- Co-Editors-in-Chief Craig Carter, Chad Autry, me
- Focus on behavioral, empirical research
- Strong contribution to theory- essential
- Managerial implications
- More in the STFs talk!

JOURNAL OF SUPPLY CHAIN MANAGEMENT

- What's hot or emerging?
  - Meta-analysis of key research areas; pinpoint overall directions, tie to theory/build theory
  - Resources--- see our STF Vol. 50 (3)
    - Also a virtual issue on-line at our website
  - Power issues on multiple levels
    - Within the supply chain- buyer-supplier
    - Within the firm– various functions and how SC fits in
    - Between supply chains
    - Adoption of dominant designs/technologies and SC power issues
  - Multi-level SC research
    - Looking at same issue on multiple levels-
      - Ex: buyer supplier alliance at individual level- buyer and salesperson/rep and at the business level- company to company
  - Research that contributes more to a theory of supply chain management
    - Establish this discipline further

THE MANUFACTURING LOCATION DECISION- WHERE'S THE VALUE NOW?

- Combine several studies, observations to bring you my conclusions
- Long-term student/observer of outsourcing and offshoring
- Research Questions:
  - What factors have the most influence on manufacturing location decisions in the near term?
  - What factors are seen as important drivers of risk perceptions in various regions across the globe?
  - How does what we perceive in the SCM operations of the company compare to what top management perceives and what we see in practice?

CSCMP OFFSHORING-OUTSOURCING STUDY (US-CENTRIC)

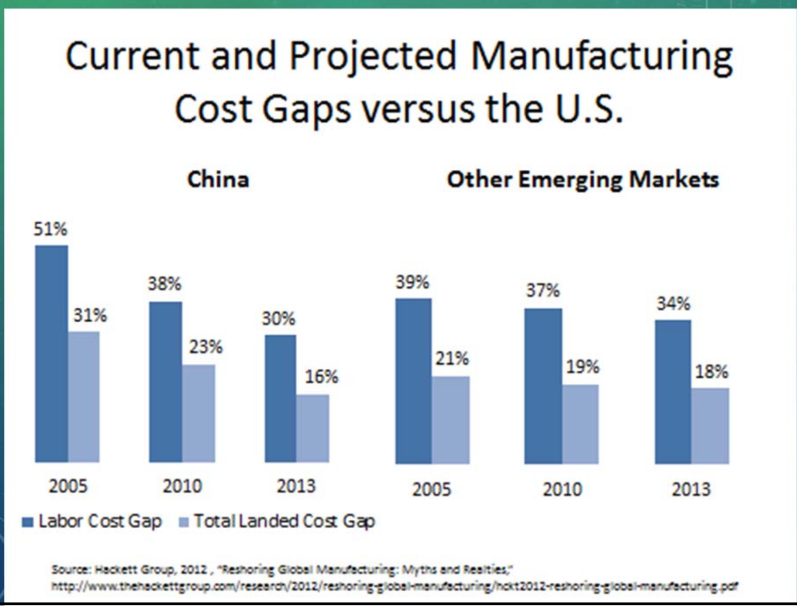
- CSCMP sponsorship
- Anecdotal evidence of trends in the public press (offshoring, nearshoring, homeshoring)
- Understand the current and future state of sourcing location trends
- Understand the key criteria used to make sourcing location decisions
- Contrast this with emerging trends in the location decisions

Co-Authors Wendy L. Tate, Tobias Schoenerr and Kenneth Petersen

DRIVERS OF GLOBAL MANUFACTURING LOCATION DECISION

- The rising cost of fuel, rising cost of labor, increased transportation costs (Behar and Venables 2010; Fishman 2012);
- The slowing of the global supply chain due to the shipping industry adoption of slow steaming (Hull 2005);
- The improving ratio of U.S. labor output /productivity per labor dollar (Anon 2012; Fishman 2012);
- Real and anticipated volatility in currency valuation (Culp 2012);
- Increasing theft of intellectual property when dealing in global regions (Clarke 2012; Riley and Vance 2012);
- The fast response time and leaner supply chain associated with locating manufacturing closer to the end customer/consumer (Williamson 2012)

DRIVERS OF RESHORING: LABOR COSTS

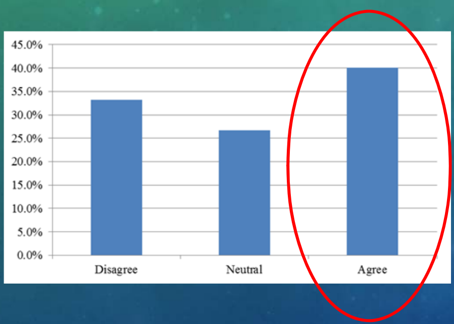


METHODOLOGY

- Online survey in the U.S. manufacturing industry
  - Launched in July of 2012
- Qualifying question: Included only those respondents that practice offshoring
  - "the manufacturing of a physical product by a firm in a country other than that firm's home country"
- Screened out participants that provided only partial answers or completed the survey too quickly
- Total of 319 valid responses

TRENDS IN MANUFACTURING LOCATION DECISIONS

Trend of manufacturing plants moving back to the U.S.



Competitors considering moving back to the U.S.

TRENDS IN MANUFACTURING LOCATION PRACTICES – OVERALL RESULTS

- 40% of those surveyed perceive a trend toward reshoring of manufacturing to the U.S.
  - Industries with strongest agreement of increased movement:
    - Aerospace and Defense
    - Industrial Parts and Equipment
    - Electronic Manufacturing
    - Medical and Surgical Supplies
- 37.7 % indicated that their direct competitors have reshored
  - Industries with strongest agreement:
    - Aerospace and Defense
    - Food and Beverage

CONSIDERATIONS INFLUENCING OFFSHORING AND RESHORING DECISIONS

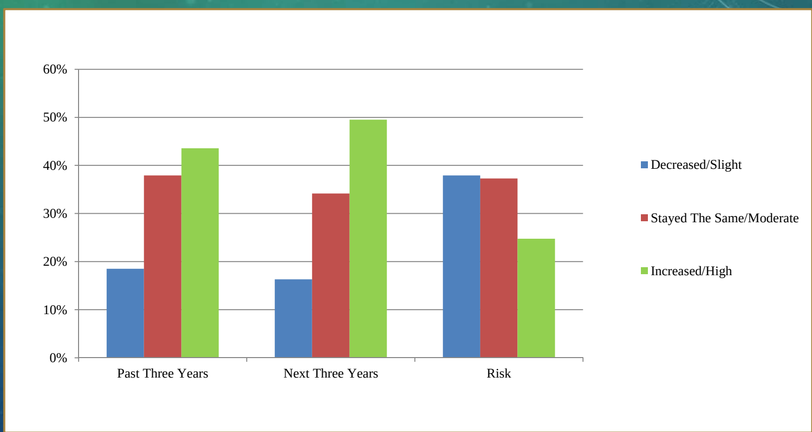
- Manufacturing location considerations
- Logistics considerations
- Customer and supplier considerations
- External environmental considerations

- Has the importance of this factor increased or decreased in the past three years?
- Do you expect the importance of this factor to increase or decrease in the next three years?
- What is the perceived risk associated with this factor?

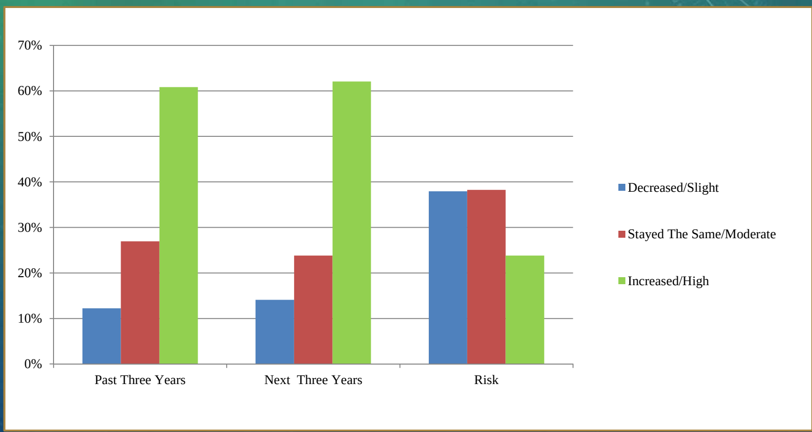
WHAT WERE THE BIGGEST ISSUES IN OUR FINDINGS?

Costs of Switching/Setting Up Operations in that Location

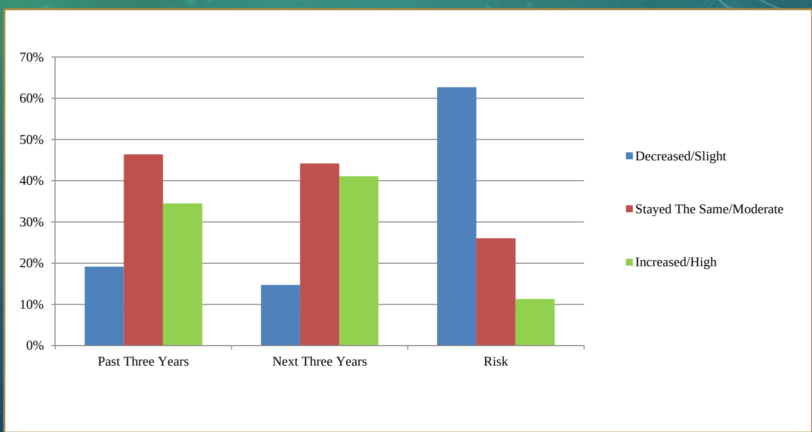
STABILITY IN LABOR COST OVER TIME



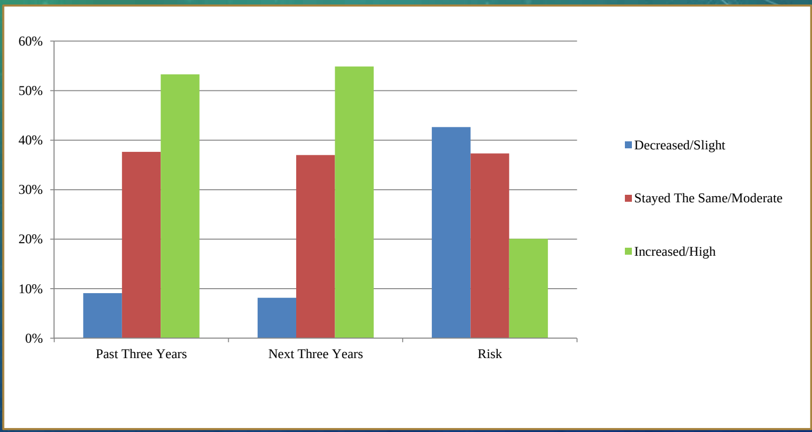
STABILITY OF TRANSPORTATION COSTS – OVERALL



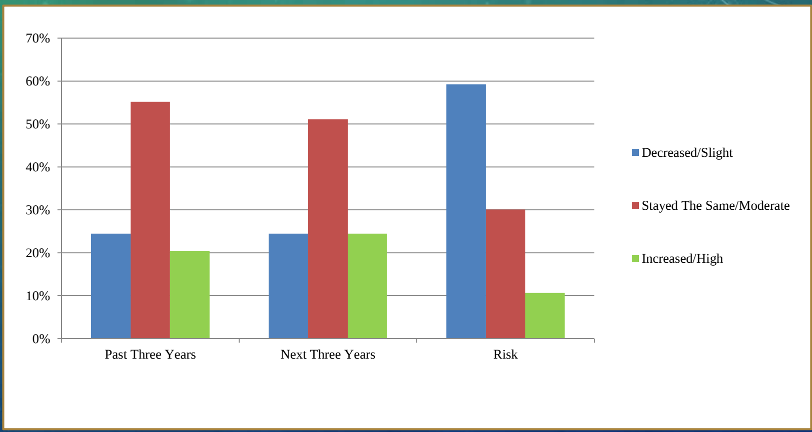
POTENTIAL TO BUILD A LOCAL CUSTOMER MARKET – OVERALL



CUSTOMER PRESSURE/EXPECTATIONS



TAX ADVANTAGE INFLUENCE ON LOCATION DECISION



IS IT POSSIBLE THAT SCM IS SIMPLY NOT AWARE THAT SOME DECISIONS ARE MADE PRIMARILY FOR TAX REASONS?

- Late 1990s, worked with HP on leveraging its volume with suppliers-
    - To retain the discounts that their volume warranted
    - Not allow their get discount on materials to be passed on to competitors
    - Buy-sell process now accounts for about $20 billion in purchases and represents nearly half the company's supply chain spending.

WHAT DOES IT LOOK LIKE?

THE REAL OPPORTUNITY EXISTS IN CHANGING THE WAY THAT REVENUE IS RECOGNIZED

Courtesy of Corey Billington

Courtesy of Corey Billington

PRIMER- HOW DOES TRANSFER PRICING WORK?

Billington, Davis & Ellram 2014

TRANSFER PRICING LAWS MAKE THIS POSSIBLE

- Locate foreign purchasing office in a low tax country
- Take profits for handling in that country
- Items may never have to physically enter that country

OR

- Manufacture in a low tax country
- "Sell" to yourself at market price, retaining profits in low cost country
- Very attractive if you sell in that country; may also be nice for export

EFFECTIVE TAX RATE COMPARISON

Effective Tax Rates, per Company 10Ks					
	FY99	**FY00**	**FY01**	**FY02**	**Ave.**
HP	26.0%	23.0	11.1	12.3	24.8
IBM	34.4	29.8	29.5	29.1	30.9
Dell	29.9	32.0	30.0	28.0	30.1
Compaq	39.1	32.0	27.2	n/a *	

IMPACT ON CASHFLOW AND PROFITS

- FY 00--$1.4 bill operating earnings * 9% higher taxes = $168 mil saved; 19% higher- $266 mil
- More complex than this- but magnitude is huge
- How can we in operations compete with an artificial affect of this magnitude?
- “Tax engineering”
- Corporate tax rate table-global
    - http://www.kpmg.com/global/en/services/tax/tax-tools-and-resources/pages/corporate-tax-rates-table.aspx

TAX COMPLEXITY IS VAST

- Corporate income tax
- Duties and tariffs still have an impact
  - Vary significantly by country, type of good, MFN status, negotiations, etc…
  - Has a direct impact on physical flow of materials
  - EX: Brazil- bring in ink and empty cartridge- duty + tax= 18%; bring in completed cartridge 63%
- VAT breaks for products manufactured in the country
- Local breaks from property and local taxes
- Inventory tax
- Many individual negotiations
- Tax dynamics

SIGNIFICANT EXAMPLES

- Microsoft "sold" the right to market products in the Americas to an offshore subsidiary
  - Subsidiary makes profits– avoided $4.5 bil in US taxes in 3 years
- Probes of shady tax dealings in the EU
  - Apple- Ireland
  - Starbucks- Netherlands (now rumored to be moving the UK for a sweet deal)
  - Fiat- Luxembourg

CEO- MAXIMIZE SHAREHOLDER VALUE

- Focus on top line- revenue generation
- Bottom line- profit---tax is often the largest deduction
  - SCM focus if generally on input cost comparisons
- US CEOs focus heavily on tax policy, lobby
- Much attention in the EU

TAX POLICY

- Tax policy potentially is an extremely sophisticated economic policy tool
- It is not an area of research and practice for most SCM people
- Has a profound impact on manufacturing location decisions an more
- Affects different companies and industries differently at different points in time

SHIFTING OF PRIORITIES IN OFFSHORING OUTSOURCING- WHAT DO WE VALUE??

- Pre- 2010
  - Demand location
  - Labor cost
  - Material cost
  - Transportation Cost
- Today
  - Demand location
  - Tax policy
  - Transportation Cost
  - Production cost
  - Material cost

David Closs, SC Quarterly

AS GLOBAL SUPPLY CHAINS HAVE MATURED, SO HAS GLOBAL TAX PLANNING FOR SUPPLY CHAINS

- Limited literature in SCM/Operations--- not our area
- We don't study implications of foreign investment
- Tax laws are in constant flux
- Tax laws/breaks are highly negotiable
- Work to balance the benefits of a good manufacturing location with available/capable resources with tax issues

TAX ISSUE IS NOT GOING AWAY

- Politically charged issue
  - US– companies have been brought before congress
    - Caterpillar- explain its Geneva affiliate that sells parts in Europe
    - Apple and Irish subsidiaries accused by US congress of tax evasion
  - EU- probes into tax advantage that companies have been given
- No real way to stop these deals
- Often viewed as unsavory-
  - "un-American not to pay your fair share"
  - "UK's "patent box" rules are not in the European spirit"
- Consulting firms are all over these opportunities
- We need to be part of the conversation

The Patent Box legislation has been introduced to encourage innovation by providing an incentive for companies to "locate their high-value jobs associated with the development, manufacture and exploitation of patents in the UK and maintain the UK's position as a world leader in patented technologies"

TREND IS REMINISCENT OF MOVE TO CHINA FOR MANUFACTURING

- 20+ years ago, VALUE we were seeking was all about low PRICE
- Chasing low labor costs and lax environmental, health & safety standards in China
- Now- chasing low tax rates around the world
- Hi –tech sector has known this for two decades
- Other industries are rapidly figuring this out
- New factor– and a powerful factor in the location decision

CHALLENGE

- What should SCM be doing about this shift in emphasis towards taxes?
- How can we incorporate it into long term as well as day-to-day decisions?
  - Avoid the Boeing 787 debacle
  - Late
  - Billions over budget
  - Huge quality problems
  - Taken off-line
- How can we influence these location decisions that effect our operations?
  - Infrastructure issues, other capabilities
  - Potentially dynamic nature of tax breaks
- How can we contribute to holistic decision making beyond tax advantage?

WHERE DO WE GO FROM HERE?

- SC perspective, strategic and managerial implications:
  - Case studies- understanding more explicitly how various costs are factored in, and outcomes measured in offshoring with a tax focus – Transaction cost analysis with total cost of ownership
  - Global network research– Map supply chains and tax rates to understand the magnitude of flows and savings from tax policies – Social network analysis/theory
- Global macroeconomic perspective, global policy implications
  - Macroeconomic data (if available) to understand impact of tax incentives and other cost factors on global supply chain configuration at a macro-level
  - In a competitive international economy, only supply chains with efficient configurations can survive. Supply chains adopt the configuration we observe, not because successful firms have chosen them, but because only firms that choose them can survive. In the long run, it is the economic logic of global competition that prevails - Mark Casson, JSCM 2013

COMMENTS, DISCUSSION

Supply Chain Evolution - An Emerging Science

Professor Bart L MacCarthy
Professor of Operations Management, Nottingham University Business School

Abstract
Supply chains are not static – they evolve in terms of size, shape and configuration and in terms of how they are coordinated and managed. New supply chains may emerge for many reasons, e.g. in response to a technological breakthrough, the emergence of a new market niche or a new geographical market. Supply chains also decline and die when demand is no longer sufficient to drive the chain. Although the supply chain management literature does address supply chain strategies and their dynamics over time, and to some degree addresses changing supply chain configurations, less attention has been given to supply chain birth and supply chain evolution from emergence to growth and maturity - what we term here as the supply chain lifecycle (SLC). Examples are given of supply chains that are mature and relatively unchanging, those that are emerging, and those that are in transition or subject to disruption. A range of sectors is discussed including steel, clothing, electronics, aerospace and the auto-industry. The major factors influencing a supply chain over its lifecycle are discussed including technology, economics, regulation and policy, markets and sourcing, and supply chain strategy and re-engineering. A number of propositions are presented on factors affecting the 'complexion' of a supply chain over its lifecycle. It is argued that a new science is needed to investigate and understand the supply chain lifecycle. This needs to exploit a wide discipline base to better understand the patterns of supply chain emergence from birth to maturity and decline.

SUPPLY CHAIN EVOLUTION - AN EMERGING SCIENCE

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UNITED KINGDOM · CHINA · MALAYSIA

B L MacCarthy *Cambridge International Manufacturing Symposium* *12 /09/14*

Agenda

1. Some examples – mature, new and in transition – steel, clothing, electronic data storage, aerospace, automotive
2. Auto-industry - technological change and impact on supply chain
3. Factors influencing supply chain evolution
4. A new science of supply chain evolution

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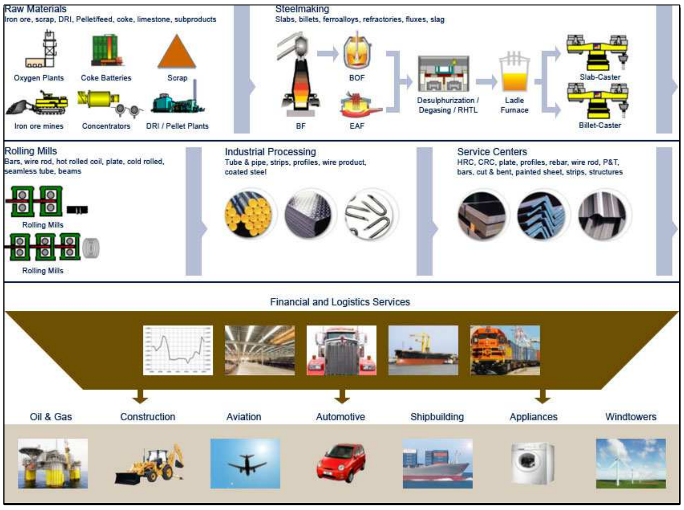
Steel – mature supply chain



http://www.cnfinternational.com/aboutus.html

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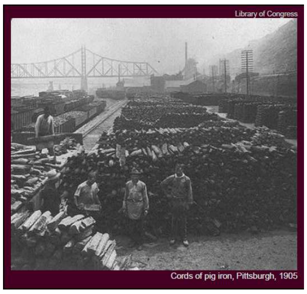
Steel – mature supply chain

Frederick Winslow Taylor, 1911

Taylor (1911), The Principles of Scientific Management, Harper, NY.



Cords of pig iron, Pittsburgh, 1905

Bethlehem Steel Works, Bethlehem, Pennsylvania, 1896

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Clothing supply chains

MacCarthy & Jayarathne (2010, 2013)

'Mature' production technologies

but remains a 'low tech' industry

Many changes in global clothing supply networks

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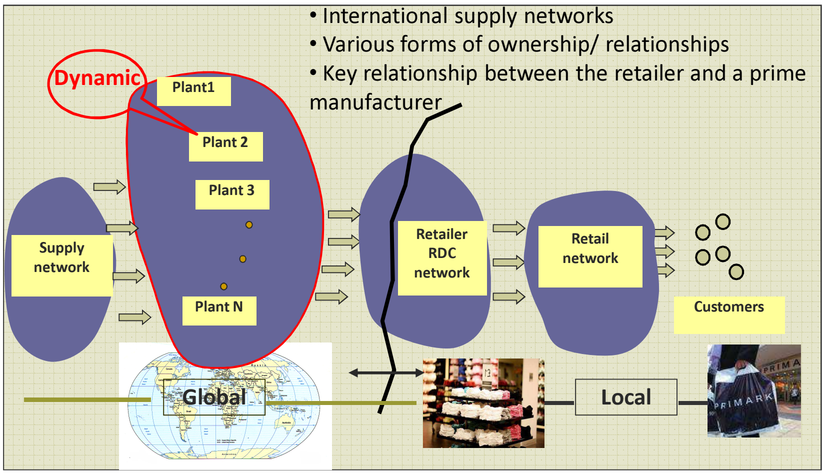
International clothing supply network- Retailer/brand-owner/buyer-driven



MacCarthy & Jayarathne (2010)

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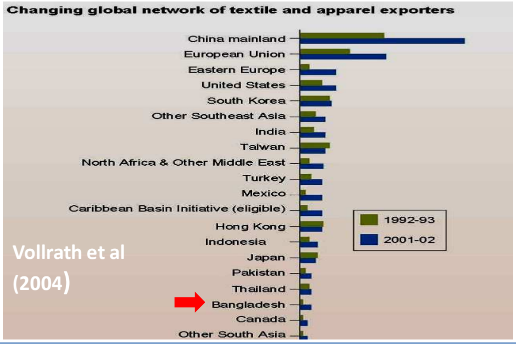

Developing country suppliers and the global apparel market 2005-2011, USD millions, current

Exporter	2005	2011	Percentage change (2005-11)	% of total exports in 2011
China	74,162	153,773	107%	37%
Bangladesh	6,889	19,938	189%	4.80%
India	8,738	14,364	64%	3.50%
Turkey	11,833	13,947	18%	3.40%
Viet Nam	4,680	13,153	181%	3.20%
Indonesia	4,958	8,045	63%	1.90%
Mexico	7,305	4,637	-36%	1.10%
Malaysia	2,478	4,567	84%	1.10%
Pakistan	3,603	4,549	26%	1.10%
Cambodia	2,210	4,050	83%	1%
World Total	278,000	412,000	48%	

Source: WTO database.

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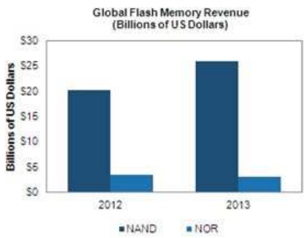
Flash memory - new supply chains

Technology patents barely 25 years old !

SCs started to emerge late 90s' !

NAND hits a record year, while NOR Flash shrinks further
25/2/2014
www.electronicsnews.com.au/news/



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The Dreamliner – a supply chain in transition

BOEING

- Boeing announced in **2003** a radical new design for their new 787
- Planned to fly commercially in **2008**
- First **test flight** Dec **2009**
- Still way behind schedule on deliveries

- **Designed with radically new technologies (composite material airfame)**
- **The new supply chain did not meet the 'scale up' challenges**

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A supply chain failure?

BOEING

Boeing's first 787 Dreamliner delivered to Japanese carrier All Nippon Airways on Sept. 25, 2011, **3.5 years behind schedule**, after regulatory approvals of the world's first plastic-composite jet.
Bloomberg

- **Repeated and significant programme delays**
- A project management failure?
- A quality management failure?
- A **supply chain failure**?

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Is the future electric?

'Green Pope' presented with electric car
BBC news, 6/9/2012

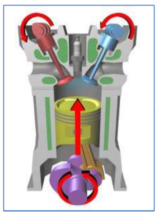
Tesla's CEO, Elon Musk, Allowing open access to its technology to promote hybrid and electric vehicles
www.inautonews.com

Have we reached a tipping point for alternatively powered vehicles (APVs) ?

The auto Landscape – competing APTs

- BEV
- FEV
- HYBRIDS

v



- ICEV

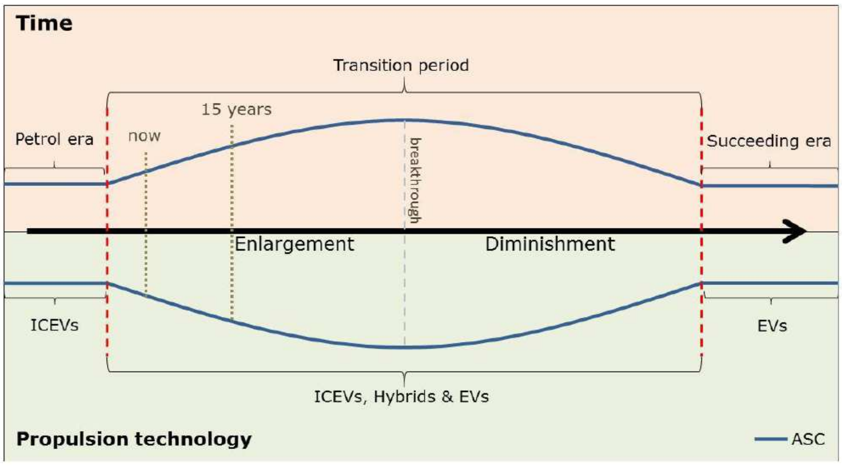
The automotive sector remains in **technological 'lock-in' with ICEV**

- Economics and modularity
- Improvement in performance of ICE
- ICE still dominant - hybrids winning in APTs

(Christensen & Budde, 2011)

How will changing technologies change SCs and SCM?

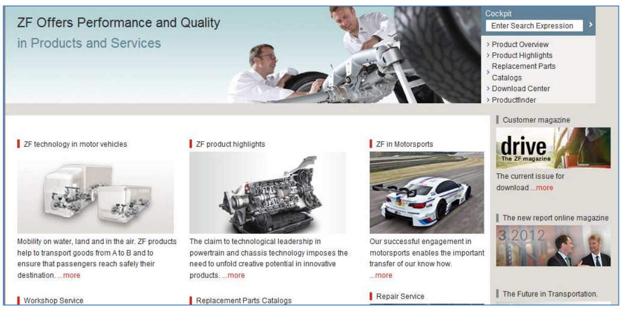
Automotive SCs in the transition period



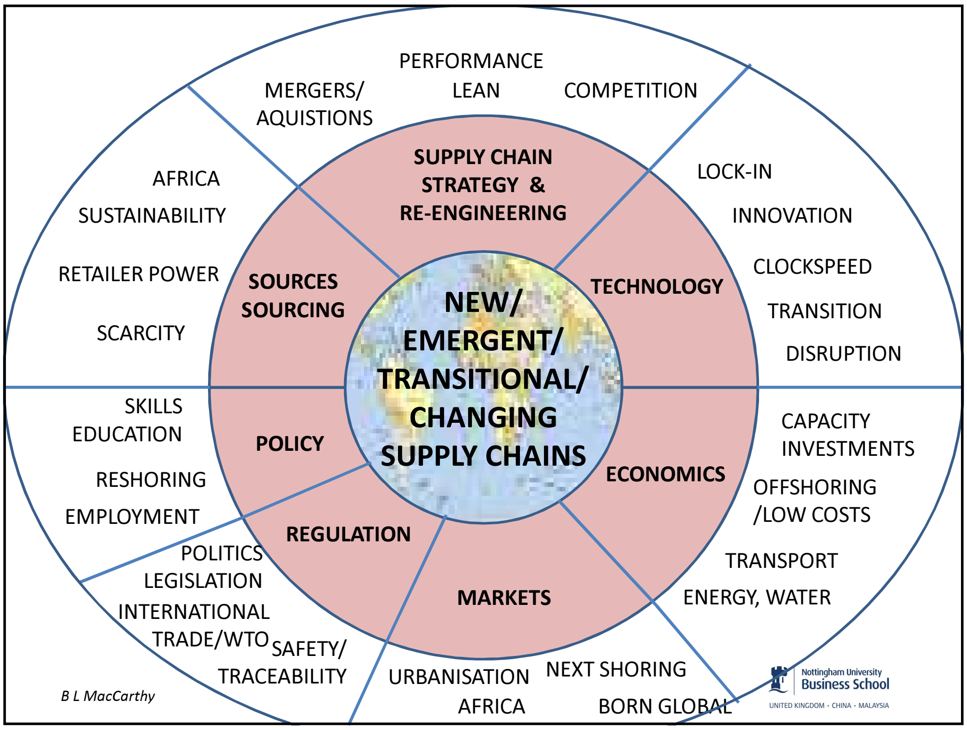
Muller&MacCarthy, Nottingham, 2012

Power in powertrains

- Who will have the power in the emergent automotive supply chains?



ZF- Will they survive, thrive or wither?


PERFORMANCE
MERGERS/ AQUISTIONS
LEAN
COMPETITION
SUPPLY CHAIN STRATEGY & RE-ENGINEERING
AFRICA
SUSTAINABILITY
LOCK-IN
INNOVATION
RETAILER POWER
SCARCITY
SOURCES SOURCING
NEW/ EMERGENT/ TRANSITIONAL/ CHANGING SUPPLY CHAINS
TECHNOLOGY
CLOCKSPEED
TRANSITION
DISRUPTION
SKILLS
EDUCATION
POLICY
CAPACITY INVESTMENTS
RESHORING
EMPLOYMENT
ECONOMICS
OFFSHORING /LOW COSTS
POLITICS
LEGISLATION
INTERNATIONAL TRADE/WTO
REGULATION
MARKETS
TRANSPORT
ENERGY, WATER
SAFETY/ TRACEABILITY
URBANISATION
AFRICA
NEXT SHORING
BORN GLOBAL
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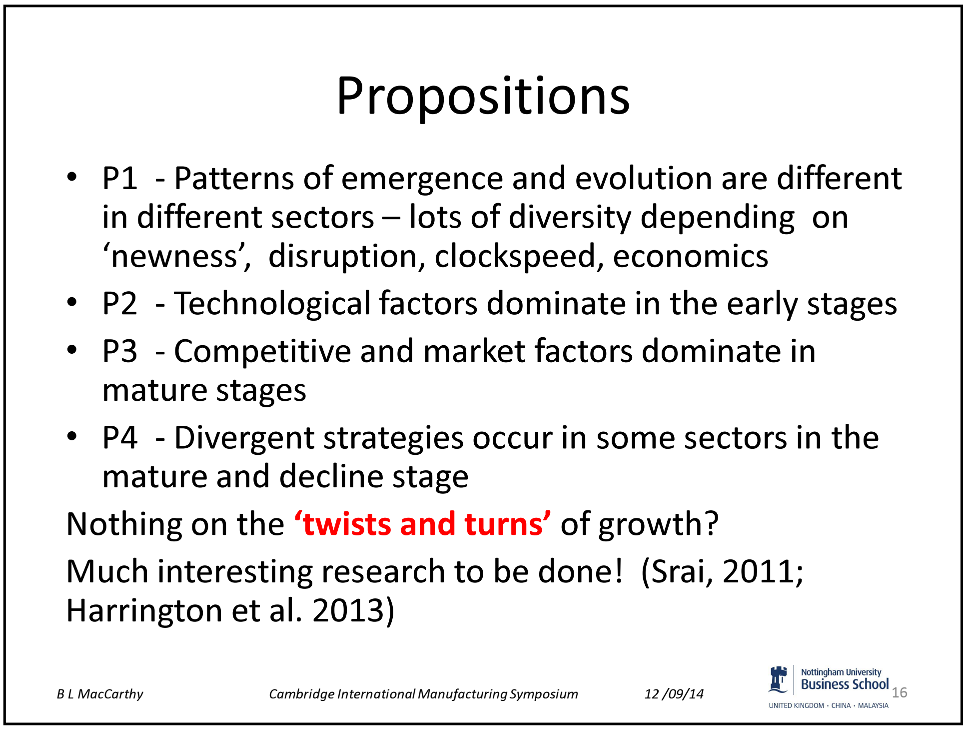
Propositions
• P1 - Patterns of emergence and evolution are different in different sectors – lots of diversity depending on 'newness', disruption, clockspeed, economics
• P2 - Technological factors dominate in the early stages
• P3 - Competitive and market factors dominate in mature stages
• P4 - Divergent strategies occur in some sectors in the mature and decline stage
Nothing on the 'twists and turns' of growth?
Much interesting research to be done! (Srai, 2011; Harrington et al. 2013)
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SCM research and theory bases

Theory bases

- **Structure, configuration and coordination** e.g. Halldorsson et al. 2007.
- **Strategy, governance and power**, e.g. Pilbeam et al. 2012
- Broader theory bases around
- RBV, Agency theory, Institutional theory, Value chain

Technology impact in SCM?

- Quality in the supply chain
- Supplier development
- Supply chain risk management
- Purchasing & procurement

- New Product Development
- Project and program management
- Innovation management
- Technological forecasting

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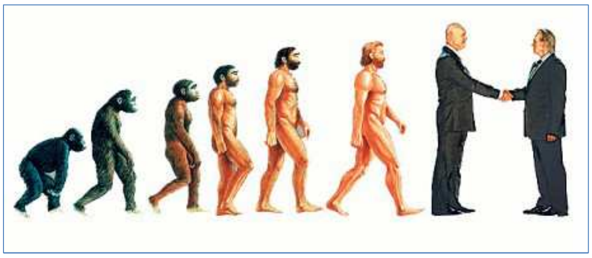
A new supply chain science to understand the **supply chain lifecycle**

- We need a new science of **Supply Chain Evolution** that marries our existing theory base with other relevant domains
- **The Supply Chain Lifecycle** - emergence , growth, maturity, decline



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The new supply chain science – understanding the supply chain lifecycle

- A **‘science’** is both a body of knowledge and a process
- Should be
  - Useful
  - Exciting
  - Needed
  - Require a global effort

We need more inputs to understand SC emergence , maturity, decline - the supply chain lifecycle

Potential contributory disciplines

- Economic geography
- Economic history
- Industrial ecosystems
- International trade
- Technology forecasting
- Product development
- Policy studies……

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Questions/discussion

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Journal	2013 Rank*	2013 Impact Factor	2012 Rank*	2012 Impact Factor	2011 Rank*	2011 Impact Factor	2010 Rank	2010 Impact Factor	Acceptance Rate**	# External Reviewers**
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Journal of Operations Management	1	4.478	1	4.44	1	4.382	2	5.09	7-9%	3
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Management Science	5	2.524	5	1.859	4	1.733	8	2.22	7%	2
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IJOPM	11	1.518	13	1.252	10	1.127	12	1.81	21-30%	2
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Example of past Special Topic Forums (STFs) and Discussion Forums

- STFs:
  - Theory Building Surrounding Sustainable Supply Chain Management- due Jan 15, 2015
  - Supply Chain Resources: Advancing Theoretical Foundations and Constructs- Terry L. Esper and Russell
  - Sustainable Supply Chain Management – Dan Krause, Rob Klassen, and Stephan Vachon
  - Supply Networks – Tom Choi and Kevin Dooley
  - Secondary Data – Roger Calantone and Shawnee Vickery
  - Global Supply Chains – Barbara Flynn
  - Service Supply Chains – Scott Sampson and Martin Spring
- DFs: Bullwhip Effect, Manufacturing Location Decisions, Qualitative Research Methods, Use of Behavioral Experiments

Process

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All Editors review submission, discuss

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We develop an announcement, publicize

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Journal of
Supply Chain Management

Special Topic Forum on Theory Building Surrounding Sustainable Supply Chain Management

Guest Editors:
Gideon Markman (Colorado State University)
Dan Krause (Colorado State University)

The area of social and environmental sustainability attracts scholars from diverse social sciences disciplines (e.g., supply chain, management, finance, accounting, marketing, political science, sociology, economics, management, etc. to name a few). Such cross-disciplinary effort is needed because although many scholars link sustainability to discrete business activities—inbound and outbound logistics, processes and operations, finished products and customer interface, distribution channels, and services—we do not have an overarching, integrative theory of sustainability.

For example, some suggest a "green to be seen" perspective—

if not all business functions. Despite the importance of sustainability, not every scholar, manager, or company agrees on the conceptual connections among and drivers of sustainability and SCM. Part of the problem is insufficient theory.

Supply chain scholars are perhaps among the most qualified to develop a theory of sustainability because they observe firms' entire value chains. Such scholarship analyzes how firms combine raw inputs from disparate suppliers; how inputs are processed and augmented into outputs; and how such outputs are then sold to customers. This also means that supply chain scholars can keenly appreciate how even seemingly incon-

Questions and comments?

The Adaptation of Supply Networks to Climate Change

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Abstract
In the current era of turbulance, organisations and their supply networks seek for effective solutions in response to a changing environment. To retain competitve, the concept of adaptation to the likely impacts of such changes has therefore become a vital success factor for organistions and supply networks. This paper addresses the changing factor ´climate change` and investigates how the global and highly exposed coffee supply network prepares to the projected impacts. Using the case study methodology and interviewing multiple organisations from all different tiers along the coffee supply chain, a network learning process towards adaptation of the entire network to climate change is developed. We argue that network learning comprises a four-step learning cycle at organisational and inter-organistional level that scales-up from smaller pilot projects to the entire network. To facilitate the network learning process, we further conclude on four enabling principles that must be translated into practical meachnisms (management actions) which may vary from network to network.

Keywords: climate change, supply chain risk management, adaptation, learning

1. Introduction

Today global supply networks operate in an uncertain world caused by changes in the political, economic, social, technological, environmental and legislative environment. A major factor expected to cause increasing uncertainty is climate change with the potential to impact all aspects of the business environment. Although many governments and organisations now recognise that climate change is happening, the predominant response has been one of mitigation, working to reduce harmful emissions and hence reduce the impact of business and logistics on the environment. Despite clear indications that climate change is happening little attention has been given to developing strategies to protect global networks from the impacts of climate change. In order to prepare organisations and their supply networks for the projected impacts, the concept of resilience and adaptation to climate change has recently attracted attention amongst academics and practitioners. Much research to date has been focused in the public sector (de Bruin *et al.* 2009; Transportation Research Board TRB, 2008) hence the overall aim of this paper is to determine, in a study of the coffee supply chain, how a global commercial network can adapt to climate change and its related risk factors.

This paper begins with a background to climate change before introducing a definition of supply chain climate risk. Having identified the research gap, the concept of learning is reviewed as a likely mechanism of network adaptation. The paper goes on to describe the primary data collection and analysis methods before presenting a process of network learning that reflects how the global coffee supply network adapts to climate related risk. It concludes with an overall assessment of the research implications and suggestions for further research.

2. Supply chain climate risk

The Intergovernmental Panel on Climate Change (IPCC 2013) concludes that climate change is inevitable. Apart from changes in mean temperature and sea-level, long-term changes in other aspects of climate have already been observed, e.g. an increase in precipitation and rising frequency and intensity of extreme weather events. Analysing the drivers of climate change, greenhouse gas (GHG) emissions in general and carbon dioxide (CO_2) in particular have been identified as key contributors (IPCC 2013).

Dependent on the average level of global warming, various effects on natural and social systems are expected. Stern (2006) groups the affected elements in five categories: *water*; *food*; *ecosystems*; *extreme weather events* and *risk of rapid climate change*. Many of the climatic and ecological projections, as well as government climate change mitigation programmes, assume incremental changes over a long period which will have diverse consequences for supply chains. In the context of this research Stern's five categories of affected elements represent *climate related risk factors* that will directly or indirectly change the political, economic, social, technological, environmental, and legislative (PESTEL) environment in which global supply chains operate. In order to assess to what extent global supply networks might be equipped to manage such diverse climate related risk factors we looked to the literature on supply chain risk and resilience.

Our review of the supply chain risk literature revealed different approaches to categorise various types of risk. Some authors investigate very precise SC risks such as *operational contingencies, earthquakes, hurricanes, terrorism,* and *political instability* (Kleindorfer and Saad, 2005); *functional and relational risks* (Svensson, 2004); *supplier capacity constraints, quality, production technologies,* and *disasters risks* (Zsidisin *et al.* 2000), for example. Others take a holistic view and provide more general categories. Christopher and Peck (2004) for example distinguish between risks which are 1) *internal to the firm*; 2) *internal to the supply network, but external to the firm,* and 3) *risks which are external to the network*. However, the literature does not specifically include climate change as a source of SC risk, nor does it recognise the likely increase in frequency and intensity of disruptive events expected as a result of climate change. In effect climate change and its projected impacts on SCs have been disregarded as a source of external risk to supply chains in the supply chain literature. Although none of the reviewed literature categorises climate change as a potential risk source, several authors (Rao and Goldsby, 2009; Juttner 2005; Speakman and Davis 2005) mention weather events, such as flooding, or refer to 'acts of god' or `natural events`. Nevertheless, with reference to Christopher and Peck (2004) all identified climate related elements, i.e. environmental and natural, fall within their last category, i.e. *risks external to the network*. We therefore add climate change and each of the five climate related risk factors as external risks to the supply network and propose the following definition of supply chain climate risk (SCCR):

> *"Supply chain climate risk (SCCR) is the probability and direct and indirect consequences to the supply chain emanating from changes in the political, economic, social, technological, environmental and legislative environment caused by climate change"*

In order to provide a solution to SCCR we look into the literature on supply chain resilience for suitable mitigation strategies. In the context of supply chain management resilience has been defined as "the ability of a system to return to its original or [...] desired state after being disturbed" (Christopher and Peck 2004, p. 2). Lee (2004) presents the triple-A supply chain to achieve SC resilience and a sustainable competitive advantage; such supply chains display the characteristics of *agility*, *alignment* and *adaptability*, to be successful in mitigating SC risks.

In the context of climate change it can reasonably be concluded that the concept of *agility* would be appropriate for responding to direct climatic impacts (e.g. extreme weather) on supply chains that require operational flexibility to maintain continuous customer service. In order to mitigate such external risks, Lee (2004) proposes the precautionary development of contingency plans and crisis management teams. Supply chain *alignment* is needed for exchange of information and knowledge as well as the sharing of risks and costs as part of the interaction between involved parties in the upstream and downstream processes. We argue that aligned supply networks improve their capabilities to absorb knowledge about the impacts of climate change through a collaborative approach and develop a mutually agreed agile and adaptive supply chain, respectively, to become resilient to a changing business environment. Finally, resilience is often thought to be related to *adaptability* (Woods 2006), and is seen as the ability to "adjust the supply chain's design to meet structural shifts in the market" (Lee 2004, p. 105). An adaptive supply chain will evolve over time addressing the reshape of markets caused by economic progress, political shifts, and technological advancement in order to gain sustainable advantage. Supporting this argument, Christopher and Holweg (2011) argue that in times of major global change, a fundamental re-think is needed in the way SCs are designed in order to maintain a competitive edge. These changes cannot be dealt with using the established concepts of efficient and agile SCs, but require 'structural flexibility'. Christopher and Holweg (2011 p. 73) argue that "supply chain design decisions are taken with the deliberate intention of building flexibility into the structure of the system". The best supply chains identify shifts, ideally before they actual occur by capturing the latest data and tracking key patterns (Lee 2004). We therefore suggest that supply chain adaptation is a key mitigation strategy to cope with current, projected continuous and long term impacts of climate change.

3. Research gap

Whereas the principles of SC resilience and adaptation are well established in literature they remain theoretical constructs. Blackhurst *et al.* (2005) comment that the literature on SC resilience is interesting, giving a good understanding of the 'big picture', but it falls short of 'drilling down' to the key variables and the methodologies to manage key issues, thus reducing the practical utility of such studies (Datta 2007). In order to understand the process of adaptation, we review the literature of learning to reveal how supply networks might adapt to climate change. As illustrated in figure 1, this research needs to emphasis the overlapping areas of supply chain risk management and learning as the former provides a solution to the problem of climate change, i.e. what needs to be done; whereas the latter offers insights into how this might be achieved.

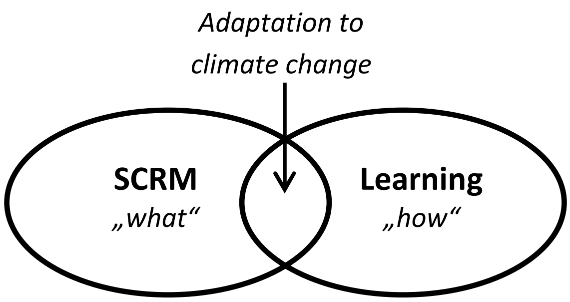

Figure 1: The research gap

4. Learning

Fiol and Lyles (1985, p. 811) define learning as "the development of insights, knowledge, and association between past actions, the effectiveness of those actions, and future actions". As such we aim to identify how the organisations in a network create *knowledge* about climate related risks and how that knowledge is translated into *effective actions* that help to adapt the network, making it more resilient to climate change. Successful adaptation should therefore depend on the ability of a SC to learn about climate change and to align knowledge on local impacts of climate change to an overall and mutual adaptation strategy for the entire supply network. Learning can happen at individual, organisational, inter-organisational, and network level (Knight 2002; Crossan *et al.* 1999, Kim 1993).

<u>Individual and Organisational Learning</u>

Montuori (2000) states that organisational learning (OL) transfers individual learning toward system thinking which prepares organisations for adaptation to the environment. Simon (1991) points out that individuals are the learning entities in an organisation as all learning takes place inside individual human heads. Accordingly, "an organisation learns in only two ways: (a) by learning of its members, (b) by ingesting new members who have knowledge the organisation did not previously have" (Simon 1991, p. 125). He further adds that learning organisations should be viewed as systems of interrelated roles and that the learning of each individual member of the firm is very much influenced by organisational structures which can either facilitate or hinder particular learning.

<u>Inter-organisational learning</u>

Stonehouse and Pemberton (1999) take the position that inter-organisational learning arises from creating accelerated synergies between linked organisations through shared knowledge and competencies. Pena (2002) takes the knowledge perspective and defines a knowledge network as "an inter-organisational agreement to share knowledge among members for the exploration (i.e. creation and development) or exploitation (i.e. product transformation and commercialization) of new technologies" (p. 472). Pena argues that besides improving internal knowledge capabilities, organisations should strengthen their network links to integrate partner skills and knowledge. However, organisations only take part in inter-organisational learning if they see a benefit for their company (Knight 2002).

<u>Network learning</u>

A network is a form of 'organisation' in which legally independent agents are linked via collaborative work and interdependent resources and activities (Ebers 1997). This paper adopts the view proposed by Knight and Pye (2004) that network learning is indicated by "changes in properties of the network (practices, structures and interpretations) that shape and are shaped by network actors, their actions and interactions" (p. 485). As such, the level of learner, i.e. the network, is influenced by the context of learning, i.e. organisational behaviour and performance as well as inter-organisational activities. Knight and Pye (2005) therefore argue that network learning is dependent on purpose, actors, operations, etc…; focuses on conceptual themes such as network structures, practices, and interpretations; and places emphasis on the development and change of meaning, commitment and method that shape the learning outcomes.

Synthesising the literature on learning, we present an *a priori* model of learning as illustrated in figure 2. The model depicts a learning process that enables supply networks to adapt to climate change. The process encompasses the two recurring phases 'understanding' and 'adaptation' that alternate in a continuous learning cycle. Each adaptation activity triggers a new cycle of learning as the newly created conditions, their effect on the environment and updated information about changes in the environment must again be understood before further adaptation. The model consists of five stages of learning: 1) Changing environment; 2) Knowledge absorption; 3) Knowledge transformation; 4) Knowledge utilization; and 5) Adaptation to a changing environment. Each stage is explained in the following sections.

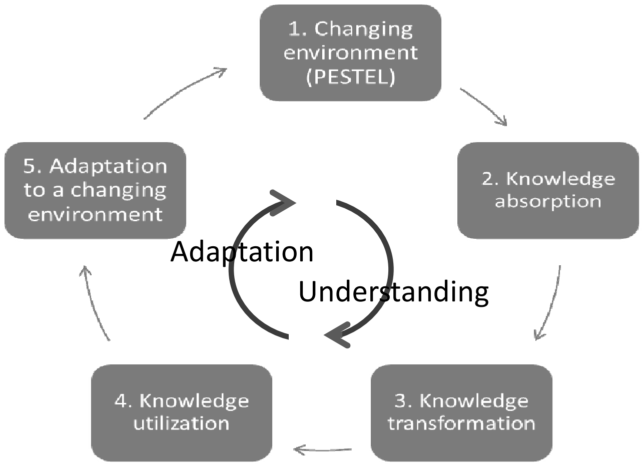

Figure 2: The learning cycle: a conceptual model of network adaptation to a changing environment

1: Changing Environment (PESTEL)
Climate change impacts supply networks via direct or indirect changes in the PESTEL environment. Changes in the environment start a new learning cycle and must be understood in detail before adapting the business in a sustainable manner.

Stage 2: Knowledge absorption
Information about environmental changes is initially converted into individual tacit knowledge. People develop individual mental models about climate change, preferably in an organisation that encourages employees to create knowledge through observation (scanning the environment), experimentation and inter-organisational knowledge transfer. As a result, potential SC climatic risks can be identified at the local level.

Stage 3: Knowledge transformation
Individually created knowledge is transformed into shared organisational and network knowledge. With reference to the high uncertainty of climate change, knowledge transformation helps to triangulate information and perceptions within the network to create a more reliable risk assessment of the impacts of climate change. To achieve this supply networks will need to include appropriate communication systems and should create a learning environment that encourages employee trust and willingness to collaborate.

Stage 4: Knowledge utilization
Shared knowledge is utilized to improve operational routines and to inform strategic decisions throughout the network. This new knowledge is then used to develop appropriate adaptation strategies to mitigate identified and understood SC climatic risks as part of a SCRM approach.

Stage 5: Adaptation to a changing environment:
The implementation of adaptation strategies may involve the redesign of organisational and supply network structures and processes such as the movement of production to locations less

exposed to SC climatic risk factors or the re-shoring of previously off-shore activities to reduce logistical exposure.

We suggest that in order for a network to learn (and hence adapt to climate change) the proposed learning cycle must be completed if not by individual organisations then jointly as a group of organisations or as a network involving a combination of individual, organisational, inter-organisational, and network learning. In the context of a network comprising multiple agents with varied functions and competencies, it is unlikely that each individual agent will complete or need to complete the entire learning cycle, hence we present the following propositions:

***P1**: Individual organisations in a supply network do not fully learn about climate change, i.e. they do not understand and adapt to climate risk.*

However:

***P2**: Networks do learn, i.e. they do understand and adapt to climate change*

5. Methodology

The field research focused on a global coffee supply network which is already weather-sensitive, i.e. relatively small changes in climatic conditions impact the extremely sensitive production process of green coffee in terms of reduced volumes and quality. Hence coffee supply chains include organisations with a heightened awareness of the possible impacts of climate change. As illustrated in figure 3, the coffee supply chain can be divided into 'core agents' and 'supporting agents'. Core agents make up the supply chain and are directly involved in production, processing and distribution of coffee. They encompass farmers or smallholder producers, traders, and roasters. Supporting agents take an advisory, educational, and moderating role. Such supporting agents include producer foundations and public enterprises for international development (implementers), standard organisations (Voluntary Sustainability Standards VSS), scientists, and consultants.

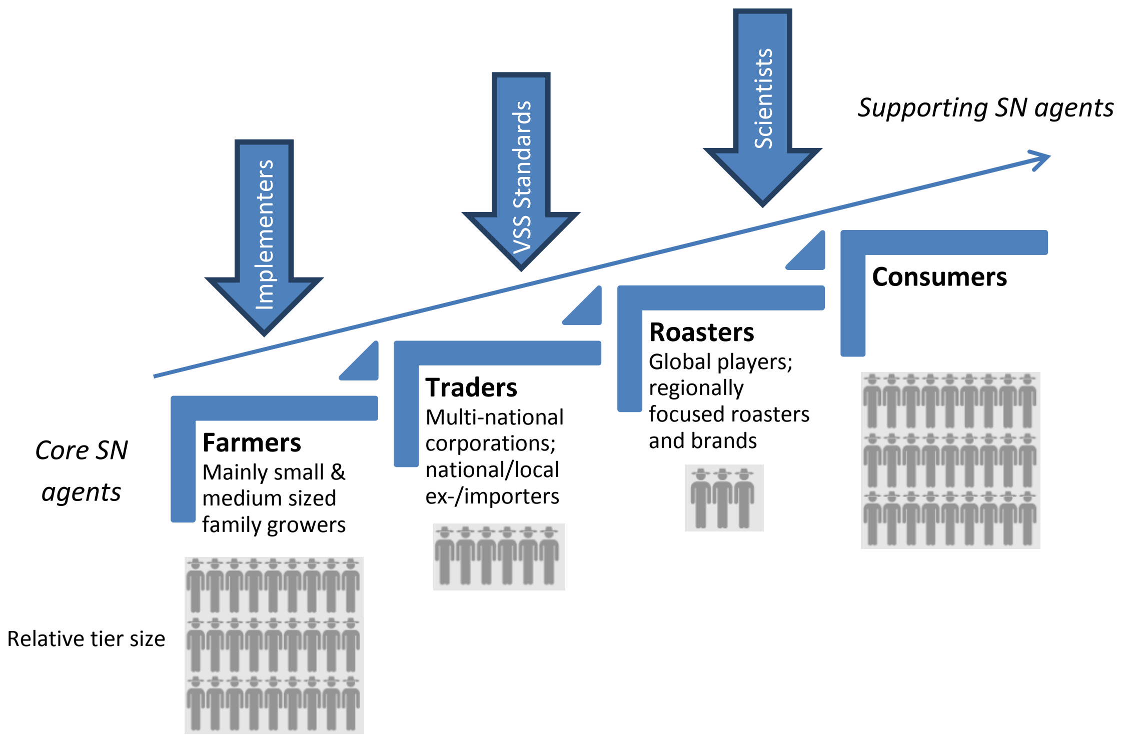

Figure 3: Representation of the coffee supply chain

The case study methodology (Yin, 2009) was adopted and empirical data collected from multiple semi-structured interviews with all core and supporting agents. In total 17 organisations (A-Q), three collaborative projects, and one sector-wide 'sustainability and adaptation' programme were investigated. Figure 4 details the inter-relationships of the agents via the three collaborative projects and sector-wide programme. The collaborative projects involved learning activities between different supply network agents, concerning different types of green coffee, i.e. Robusta and Arabica, and were carried out in different regions worldwide. Using our *a priori* model of learning, learning capabilities at organisational, project, and programme level were investigated. Interview questions were structured according to the different stages in the learning cycle. Representatives of all four supply chain tiers and all supporting agents were interviewed in order to capture a complete picture of how the network understands and adapts to SCCR.

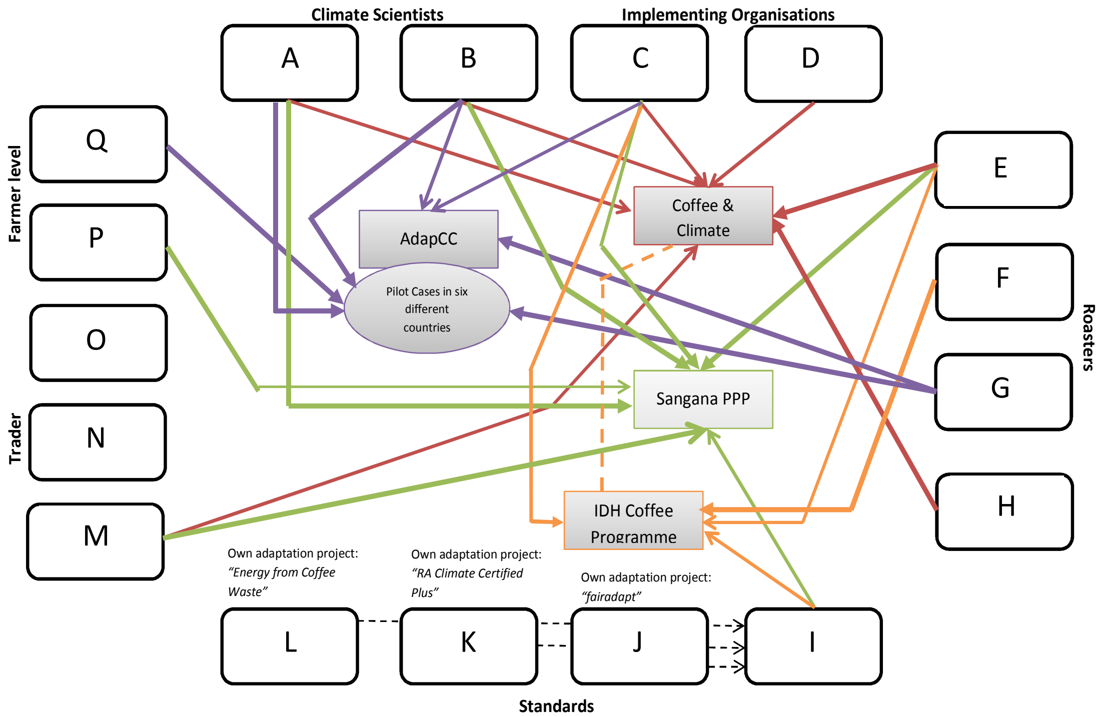

Figure 4: Agents and collaborative learning projects in the coffee supply network

6. Findings

The research reveals that none of the core or supporting agents exhibit 'very strong' competences in all four stages of the learning cycle. With the exception of the two large roasters (E and F), which have either 'strong' or 'very strong' capabilities in each step, the remaining agents have gaps or weaknesses in one or more of the learning cycle steps. Figure 5 summarises the findings in terms of organisational level learning about climate change in a matrix of knowledge creation (combining knowledge absorption, transformation and utilisation) against the level of adaptation. The figure clearly shows that a position in the top right quadrant is required to fully learn and adapt to the impacts of climate change. However, the analysis of the different supply network agents revealed that only two roasters are classified in this quadrant. Farmers and smallholders exhibit strong adaptation skills, but weak knowledge creation capabilities (beyond knowledge absorption). Traders, small roasters, and two of the standard organisations are relatively weak in knowledge creation as well as adaptation and take the least favourable position in organisational learning. Finally, the two leading standards organisations, scientists, organisations C and G are positioned in the bottom right quadrant i.e. strong knowledge creation abilities, but weak involvement in the implementation of adaptation measures.

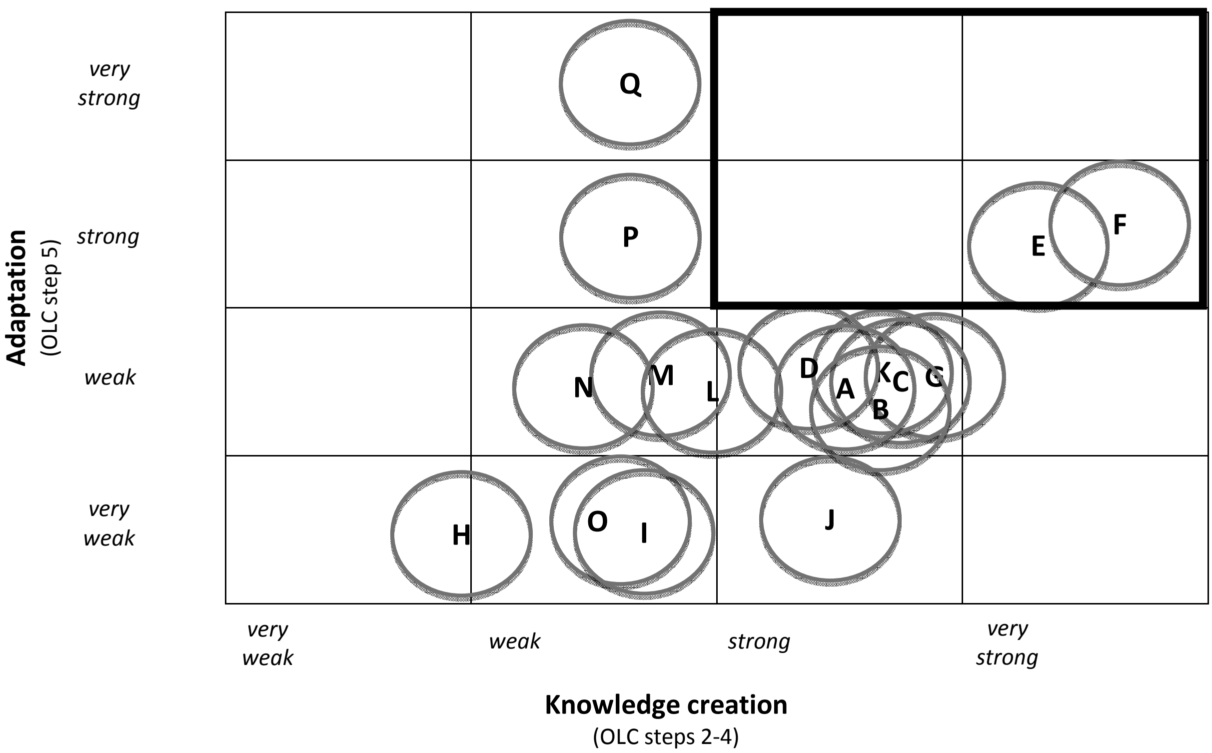

Figure 5: Relative positioning of organisations in a knowledge creation-adaptation matrix for organisational learning

This illustration of the research findings clearly shows that organisations tend to be either strong in knowledge creation or in adaptation. The findings therefore support the first proposition:

***P1**: Individual organisations in a supply network do not fully learn about climate change, i.e. they do not understand and adapt to climate risk*

Farmers are arguably the most exposed agents to climate change and are therefore well positioned to absorb knowledge, however they lack the capabilities to transform and utilise that knowledge. Through inter-organisational learning, other agents are able to use the knowledge of farmers to complete the learning cycle and finally farmers are advised and assisted in the implementation of adaptation strategies. Overall, the organisational learning of individual agents is insufficient to achieve network-level adaptation to climate change. Therefore it is necessary to investigate how inter-organisational learning is carried out.

The investigation of three collaborative 'inter-organisational' projects revealed a more successful approach to adaptation. To illustrate the findings, the 'Coffee & Climate' Public-Private Partnership (PPP)[1] project is discussed here. In a pre-competitive environment, four pilot regions and a number of global and local research institutes contributed observations and future projections of climate change. Roasters and traders then facilitated the development of a toolbox that can be accessed globally and that enables farmers and advisory services to

[1] An arrangement where a government and a profit-making company invest in and work on an activity together (Cambridge Business English Dictionary).

implement adaptation measures according to the local climate related risks. A web-platform facilitates knowledge transformation and utilization as successful examples of adaptation and new research findings are shared and applied in other regions. Finally, the collaborate approach and large scope of the project brings together multiple network agents and provides a systematic adaptation tool for ongoing use. Dependent on the organisational strengths, each agent can either contribute new practitioner and scientific knowledge, participate in the discussions to further develop the toolbox, publish examples of successful adaptation, and report difficulties during the implementation of the proposed adaptation measures. The individual agent contributions to the project can be found in appendix 1.

The investigation of the other two collaborative projects also confirmed the adaptation of some small and selected regions of the global coffee supply network as a result of inter-organisational learning to climate change. The projects are evidence that inter-organisational learning helps the network to complete the learning cycle. These projects facilitate the network learning and ultimately adaptation of the supply network to climate change as a whole, thus supporting our second proposition:

P2: *Networks do learn, i.e. they do understand and adapt to climate change*

All three investigated cases show that inter-organisational learning happened as part of public-private-partnerships and involved representatives from all core and supporting agents.

However, the research also revealed that despite some success of adaptation at small-scale project level, difficulties occurred in the alignment of strategies and activities the bigger the project. This problem might be caused by the lack of a focal company or dominating tier within the supply network as roaster and traders, and to some extend also farmers as a group, have strong market power. This lack of alignment amongst the agents on mutual norms, behavioural rules, structures, and strategies may explain the difficulties the network has aligning adaptation strategies. As learning involves adaptation, mainly at the farm level, where there are some 25 million farmers in the case example worldwide, many (local) organisations need to be involved in 'scaling up' adaptation from project to a worldwide supply base.

The collaborative projects demonstrated that close working relationships facilitated inter-organisational learning. In small scale projects, public stakeholders ensured accepted action rules and enabled knowledge creation in a pre-competitive environment. However, the challenge was to scale-up the findings to reach millions of farmers. So adaptation of the supply network is not a result of independent organisational learning, but requires co-ordinated learning approach including different levels of learners in different learning contexts as illustrated in table 1. Changes in the coffee network not only refer to changes in mental models and behaviour towards climate change as an outcome of network learning, but also require the practical implementation of adaptation measures at the farm level. For that reason, the outcome of network learning in the form of physical adaptation is also influenced by the performance of the implementing organisations.

	Context of learning	
Level of learner	**Organisational**	**Inter-organisational**
Organisation	Organisational learning of each SN agent; refers to Nonaka's (2004) spiral of knowledge creation	Inter-organisational projects such as AdapCC, Sangana PPP, and Coffee & Climate
Network	Organisations must implement the developed adaptation measures (network learning outcome) to increase the resilience of the coffee supply network as a whole.	National and international network learning programmes such as the IDH/Sustainable Coffee Programme

Table 1: Network learning in the coffee supply network
Source: adapted from Knight (2002)

We argue that at the global scale the links between stakeholders might not be as close as in smaller projects. Moreover, the level of collaboration is likely to be different amongst the agents. Therefore, the coffee supply network requires strict action rules to maintain the manageability of the development and implementation of adaptation strategies. The research revealed that an orchestrating agent (e.g. organistion `C` in the Coffee & Climate project) is needed to co-ordinate and moderate the different project learning activities. This agent ensures a pre-competitive environment with clear rules for financial and resource contribution.

7. Network learning for network adaptation

7.1 Process model for network learning

Synthesising the empirical findings from the case study, the following definition of network learning is proposed:

> *"Network learning is an integrated and co-ordinated process of knowledge absorption, transformation and utilisation by some or all network agents as a group which enables the whole network to adapt to a changing environment"*

Based on the proposed definition, a model of network learning was developed (figure 6.) The model adopts a spiral design, similar in concept to that used by Nonaka (2004), to explain the overall process of network learning. Nonaka (2004) used a spiral to model the process of knowledge creation, whereas in this model the researcher attempts to depict the process of network learning as revealed in the coffee network.

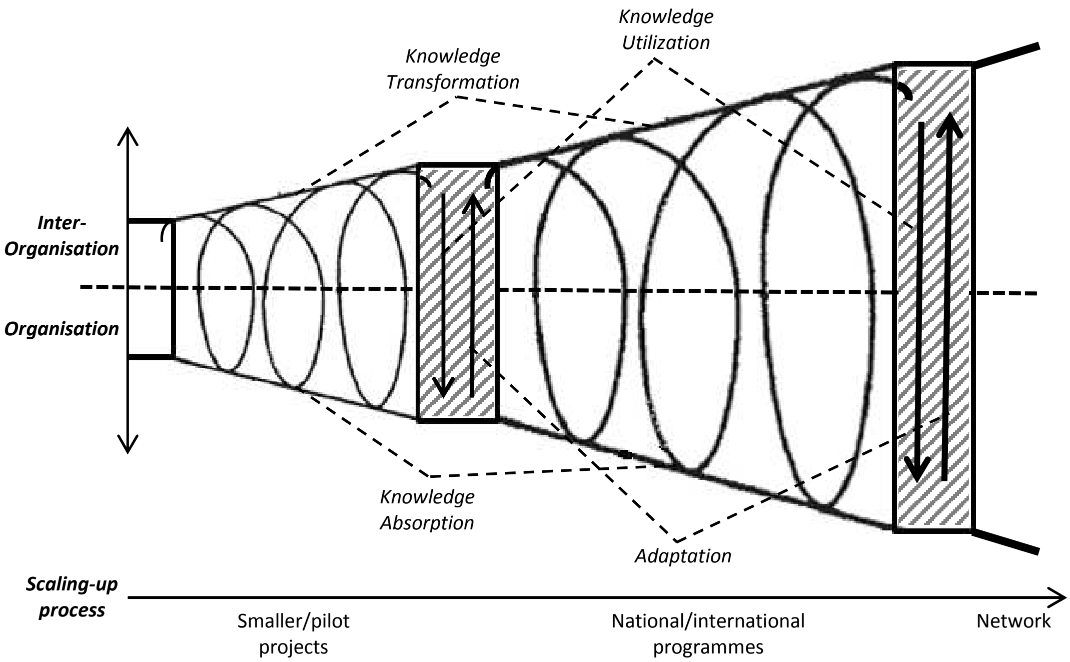

Figure 6: Spiral of network learning

A spiral design was chosen as it best illustrates the interactions between the three different and distinct elements: a) an integration of the inter-related concepts of organisational and inter-organisational learning; b) an overall recurring learning cycle that comprises the four steps 'knowledge absorption', 'knowledge transformation', 'knowledge utilization', and 'adaptation'; and c) the important role of 'scaling-up' to achieve network adaptation.

The design integrates the four stages of learning (knowledge absorption, knowledge transformation, knowledge utilization, adaptation) at different positions in the spiral moving left to right in the model. The findings reveal that some parts of the overall learning cycle occur within the organisation (knowledge absorption and adaptation) and others involve inter-organisational learning (knowledge transformation and utilization). Focusing particularly on adaptation, two different levels are addressed: First, it refers to changes in operational day-to-day routines making the supply base more resilient to climate risk; second, business habits at the organisational and inter-organisational level must be adapted to facilitate operational adaptation. In the coffee network, operational level adaptation is carried out by farmers, whereas the more strategic structural adaptation of the network is implemented by the remaining core and supporting organisations.

The nature of the investigated network, with its highly dispersed supply base and numerous organisations involved at different tiers, requires a scaling-up of the learning. Accordingly, the 'group of organisations' that learn varies as the learning progresses and scales up to network level. Initially, only selected members of the supply network learn in inter-organisational pilot projects to keep the group manageable. Based on pilot learning outcomes, further organisations can be added to the 'group' and develop changes in network practices and structures with the aim to adapt the whole network to climate change. In figure 6, the final learning step 'adaptation' is represented by two vertical arrows pointing from the organisational to the inter-organisational level, indicating that the learning outcome of pilot projects (adaptation) is the input for subsequent learning cycles in international programmes at a larger scale. The two vertical rectangles comprising knowledge utilization and adaptation emphasise the separation between the different stages in the spiral of network learning. Even though one network learning event or stage is terminated (e.g. at the project scale), it may take time to scale up. Accordingly, the boxes include the adaptation step as a final activity showing that some parts of the supply network have been adapted before complete network learning is achieved.

7.2 Enablers and mechanisms for network learning

The research identified four enabling principles and seven mechanisms that help the coffee supply network to adapt to climate change as illustrated in figure 7.

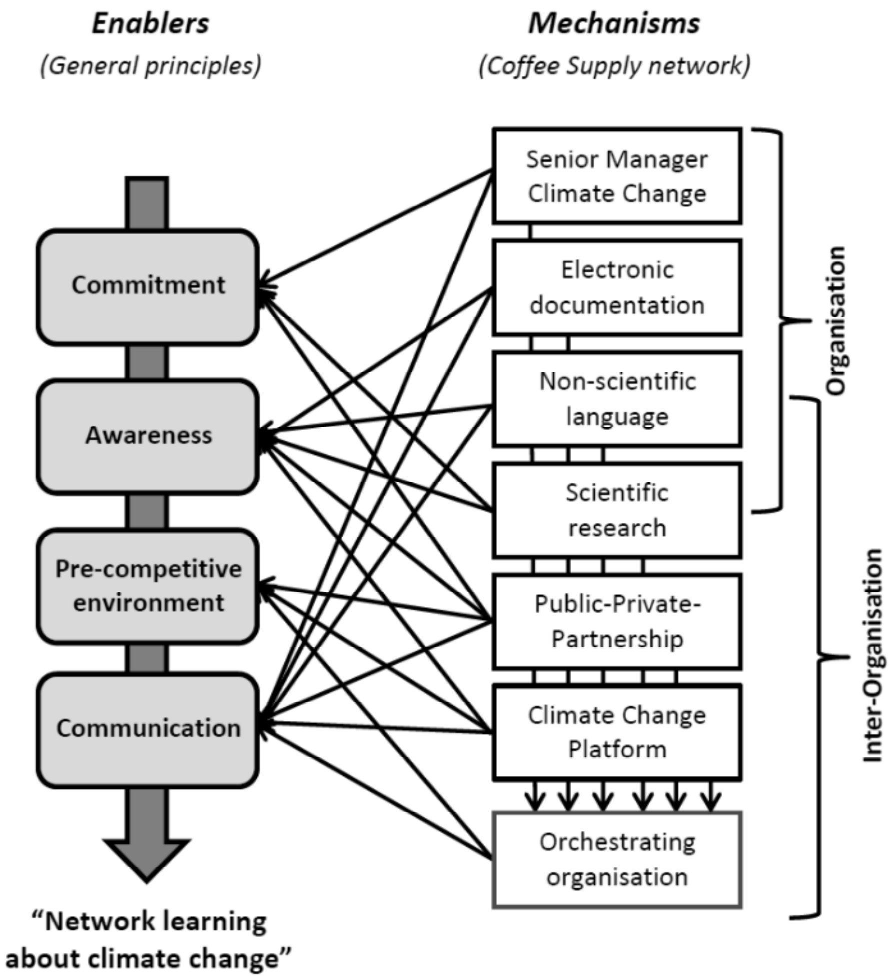

Figure 7: Relationships between enabling principles and mechanisms in the coffee supply network

The four enabling principles found to facilitate network learning include 'commitment', 'awareness', 'communication' and most importantly a 'pre-competitive business environment'. In the context of this research, *commitment* addresses the need to view climate change as an important source of SC risk and recognise the need to adapt operations and network structure. It particularly refers to the willingness to collaborate with other organisations, assimilating their ideas and engaging in the development of shared adaptation measures. *Awareness* sensitises network agents to the problem of climate change and heightens their understanding of projected environmental changes. *Communication* is needed to disseminate knowledge between agents and across the network in a comprehensible form that can be understood by the intended recipients. Dissemination of information about the benefits of adaptation measures is critical and agents must be receptive to it. Awareness and communication are both critical success factors in the scaling-up process.

It is well understood (Knight 2002) that for-profit organisations will only take part in collaborative projects if there is some benefit for the firm. The research revealed that in a network involving both not-for-profit (implementers; smaller parts of the standard organisations) and for-profit organisations (core supply network agents; main divisions and departments of the standards), a pre-competitive environment is essential to attract organisations to learn as a group for the benefit of the whole. Such a pre-competitive environment needs to create conditions under which multiple partners can work closely together without this affecting their competitive positions. Organisations will be very reluctant to participate in network learning if the setting is not in a pre-competitive environment with clear and impartial knowledge sharing rules. The findings suggest that a pre-competitive environment is essential to attract for-profit organisations to a group that collaboratively learns without seeking immediate organisational benefits. A pre-competitive environment is therefore identified as the key enabling principle for network learning.

The investigation also revealed seven mechanisms, implemented at the organisational and inter-organisational levels that translate the enabling principles into management actions. As illustrated in figure 7, the seven mechanisms are associated with one or more of the enabling principles. Some mechanisms, such as 'Senior manager climate change' and 'Electronic documentation', are implemented at the organisational level, others like 'Public-private-partnership', 'Climate change platform', and 'Orchestrating agent' apply at the inter-organisational level. 'Non-scientific language' and 'Scientific research' are mechanisms that relate to both levels. The 'Orchestrating agent' is a key mechanism required to integrate the function of all other mechanisms.

In this research, organisation 'C` was identified as an 'Orchestrating agent' in the Coffee & Climate project. This not-for-profit organisation contributed with its huge experience on the impacts of climate change on agricultural products; organised committee meetings; offered implementation support at farm level; ensured a transparent flow of finances; and guaranteed the dissamination of created knowledge to all participating agents during the period of the project. Through the creation of a public-private-partnership together with scientists (A and B), smallholders, traders (M), and roasters (E and H), the 'Orchestrating agent' C was able to create a pre-competitive environment which enabled effective network learning. The orchestrator had a deep knowledge of the sector enabling it to oversee all aspects of the learning process. Being a governmental organisation with clear objectives concerning adaptation to climate change and a neutral business model meant that organisation `C` was well suited to this role.

8. Conclusion

This paper contributes to the emerging field of research on supply chain adaptation a) by integrating different and often separated fields of research: supply chain management, climate science, supply chain risk management, learning, b) by defining supply chain climate risk and making a contribution to the theory of learning, and c) by identify how managers in complex global supply chains can enable network learning.

Although the empirical research was confined to learning in the coffee supply network, the proposed spiral of network learning model may fit similar supply networks in the agricultural sector exposed to SCCR and with a similar dispersed small holder supply base (e.g. tea, banana, etc...) or a more condensed supply base (e.g. cotton and soya). Our findings should therefore be of interest to any organisation involved in such supply networks. Each organisation, independent of size, market power or capabilities, is part of the interdependency between agents in a supply network and should participate in the network learning process.

We envisage that the spiral of network learning and the identified enabling principles and mechanisms, will act as a reference to quicker and more efficient adaptation to the impacts of climate change.

As the modelled network learning process is based on a single network case study, further research is required to determine its generalizability. Cross case analysis of multiple cases would lead to a more robust model as information from multiple networks could be triangulated to validate and refine the model developed here. The qualitative analysis in this paper could also be supplemented by quantitative analysis involving operational, market and financial data. Future research should also test the validity of a) the model in the context of risk sources other than climate change and b) the enabling principles and mechanisms of network learning. A more explanatory research approach could reveal the cause and effect relationships between the mechanisms and their impacts on the quality and success of the network learning process.

Finally, more research is needed to identify and understand the strategies that best make a supply network resilient to climate change. This could focus on operational adaptation measures such as farming practice or more strategic decisions, such as a return to localised sourcing, the climate-proofing of logistics infrastructure and building structural flexibility into the supply network. If current climate projections prove accurate and carbon mitigation efforts continue to fall short of requirement, the adaptation of supply networks to climate change is likely to become a major preoccupation of management during this century.

Appendix 1

Inter-organisational learning of the Coffee & Climate project (Vietnam case)

SN Agents	*Representing*	*Four Phases of the Inter-Organisational Learning Cycle*			
		1. Knowledge absorption	2. Knowledge transformation	3. Knowledge Utilization	4. Adaptation
B	*Scientist*	General overview of the future climate; scientific projections of climate conditions by 2020 and 2050, development of coffee growing suitability maps; decline up to 50%; more seasonality in rain and drought		Coffee & Climate Toolbox	
A	*Scientist*	General overview of the future climate; scientific projections of climate conditions by 2020 and 2050	Proposition of seven adaptation strategies to be implemented in Vietnam		
Various Smallholder farmers	*Farmers/ Local experts*	Observations and experiences of the impacts of climate change on the coffee growing process; suffering from plantlet pest and diseases, over irrigation leading to scarcity of water, extreme weather, changes in rain and dry seasons. Decline in coffee production by ca. 20% between 2010/11 and 2011/12.			Application of the developed 'tool box'; currently tested by the farmers, but no concrete progress reports available; reports expected due to be published by end of 2013
C/D	*Implementer*	GIZ represented the public partner in the PPP project and put in significant funding; contributing with first-hand knowledge of the impacts of CC. Neutral organisation that co-ordinated the different interests of all SC tiers. NF contributed solution approaches for individual tools (insufficient water supply, soil nutrition, root depth, pH analysis, pest and disease management, landslide protection, irrigation, and irregular rainfall leading to drying difficulties). NF via EDE assisted during the field testing of the tool box.			
M	*Trader*		Emphasised strongly on collaborative acti-veties to raise aware-ness of climate change; requested clear rules for collaborative projects to distinguish be-tween competitive and pre-competitive elements.		
E	*Roaster*		Represented the roasters position on CC adaptation that flows into the development of the toolbox. Emphasised strongly a pre-competitive approach on adaptation. Driving force of sector collaboration on adaptation as Tchibo is exposed to CC due to its 100% Arabica sourcing strategy		
H	*Roaster*		Contributed perspective of smaller roasters, mainly absorbed know-ledge from the transformation step in the IOL-cycle to start a new OLC-cycle.		

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18th Cambridge Symposium on International Manufacturing, Institute for Manufacturing, University of Cambridge

Supply chain resilience for Oil & Gas industry infrastructure projects

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Abstract

Oil & Gas industry infrastructure projects face the dual challenge of integrating the latest product solutions on offer, whilst ensuring their conformity to the stringent certifications required for the application. These multi-billion dollar infrastructure projects have decades of operational life expectancy with forward integration and upward gradation capability.

Leading organizations depend on the engineering expertise and trusted value chain of global integrated solution providers like ABB Group. This paper summarizes the key challenges of such projects and focuses on the three key elements by which supply chain resilience is achieved by ABB. The key elements include agile design and engineering, collaboration with suppliers and supply chain risk reviews all of which achieve the best solution created for both green-field and brown-field infrastructure projects.

The findings contribute to industry literature for the oil & gas industry to establish supply chain resilience for such complex infrastructure projects.

Keywords: Agile, e-Sourcing, Health & Safety, Risk, Collaboration

Introduction:

Supply Chain resilience is about the extent of preparedness to manage uncertainty due to various natural or man-made demands. While the Oil & Gas industry continues to be the energy life-line of the global economy, the requirements from infrastructural projects can have wide variations. While several non-conventional resources are being explored and efficiencies of existing channels of consumption have increased drastically, the global demand has an increasing trend attributed to population growth and various other events. With identification of new resources and continued investments, this industry is expected to thrive for decades to come. Expansion in the existing projects or exploration in new fields both off-shore and on-shore continue to grow this industry [1, 2 and 3].

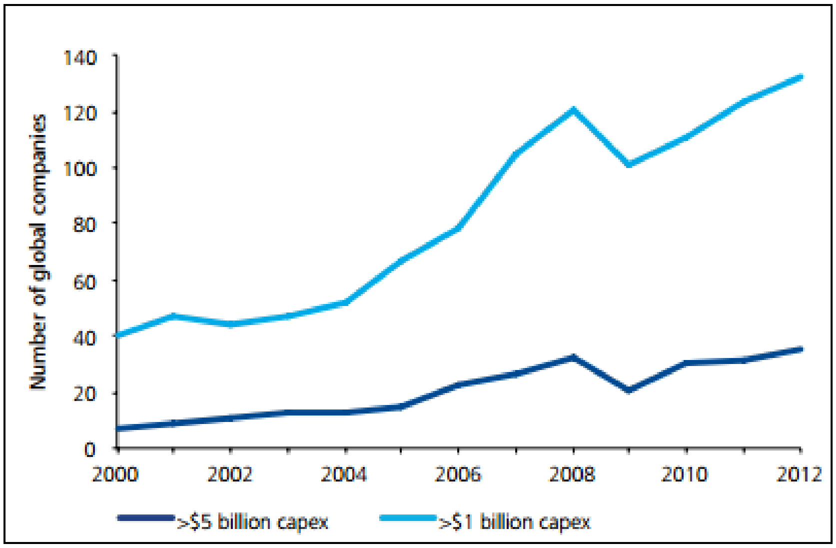

Fig 1: Number of Global Oil & Gas companies with large capital investments [10]

Globally distributed projects exist in geographies that require safety certification, product and licensing compliance to regional laws. As the demand evolves, alternative Oil & Gas resources like Shale Gas, industry forecasts still remain unclear on the extent of infrastructure investment linked to ROCI (return on capital investment). Even in this scenario, capital intensive infrastructure projects are inevitable to meet the demand. Once investment is committed, however, any disruption in project execution due to disturbance in supply chain is unacceptable. It is through supply chain resilience, preparedness is achieved to mitigate the majority of such disturbances.

This paper is structured based on execution experience of large-sized infrastructure projects for Oil & Gas industry and research towards proposed developments as part of a category development initiative for ABB's supply chain organization. The context of the paper is set out in the following section by reviewing key challenges faced in this industry. The key methods of overcoming the challenge through supply chain resilience are described in the sections 1 through to 3. The conclusion summarizes the benefits of the methods identified, along with threads to continue further research in this area.

Challenges of Oil & Gas industry infrastructure projects

Oil & Gas infrastructure projects can be in extremely diverse geographies, from El Merk Oil & Gas fields in Algeria to floating Oil & Gas platform in Barents Sea [6, 7]. Wide variation in the project locations, environment and infrastructure requirements acquire several supply chain challenges from initial project engagement, through project execution, post installation support and maintenance during the operational life cycle of the project.

For green-field projects, health and safety of the field personnel is the primary challenge for project execution, mainly due to projects in isolated locations.

A project's geography can be either in a desert or on the high seas, posing newer threats to transportation of material, skilled man-power availability and cost containment linked to ROCI

[Figures 8, 9]. Regulatory changes due to ecological concerns, lead to political pressure, which is typical for new infrastructure developments.

Brown-field projects which would have been operational for decades also have additional challenges: evaluating new technologies, integration of new equipment to the existing facilities whilst maintaining operations.

A common integration challenge for both green-field and brown-field projects is that products are designed to be interfaced to their own brand equipment in the forward or backward scale which determines the level of conformity to product certification standards; ensuring the right suppliers are selected continues to be another common challenge.

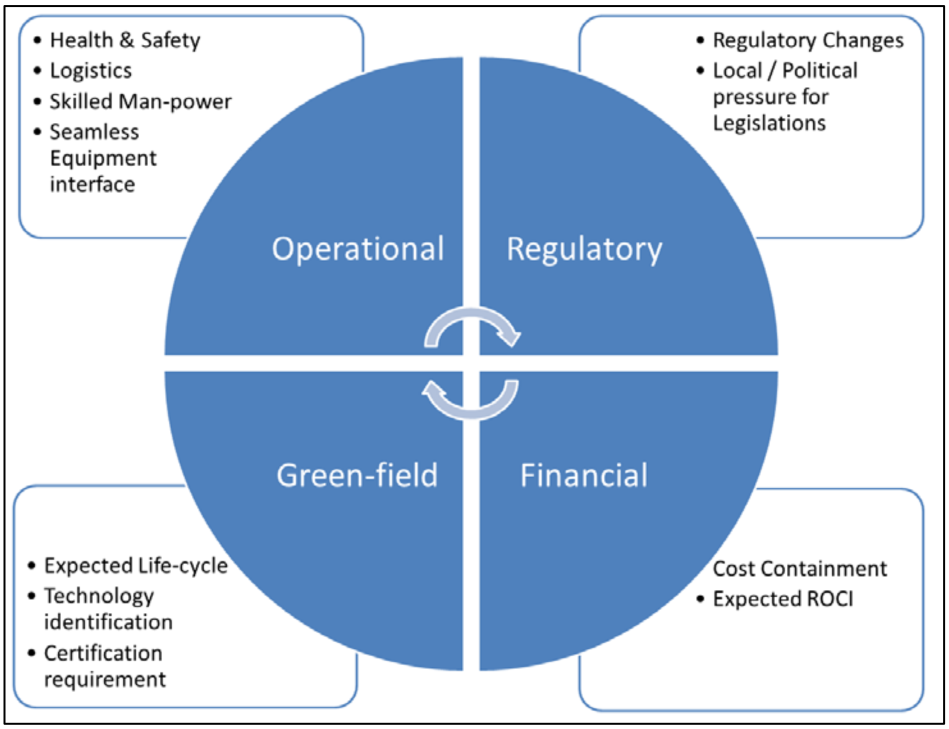

Fig – 2: Summary of challenges in Oil and Gas infrastructure projects

Achieving resilience in supply chain

1. Agile design and engineering

The Oil & Gas industry's move towards Modular design standardization has benefited projects through efficiency of design and engineering solutions. Experts have shown through analysis that modular design can be standardized for up to one-third of the design, even for the most complex systems. [13]

High agility to modular design comes with the introduction of a global Core Technology Team from various disciplines within an organization who create a library of sub-parts from various manufacturers. This team brings in experiences from various geographies, scales of project execution and the involvement of multiple disciplines, as well as the values of large organizations in effective query resolution coming from such a central approach. A structured approach to supplier data management through part qualification helps to maintain conformance to the latest industry certifications. This can be very effective in the execution of complex engineering projects through obsolescence management, as well as bringing in latest equipment to the proposed solution.

All this can be further developed using a supplier collaboration platform where access is provided to pre-qualified suppliers who can then log-in to the designated platform and submit the proposed product details in a pre-defined format to the organization. The details provided are reviewed by the Core Technology Team and considered for inclusion in the parts library after required due diligence.

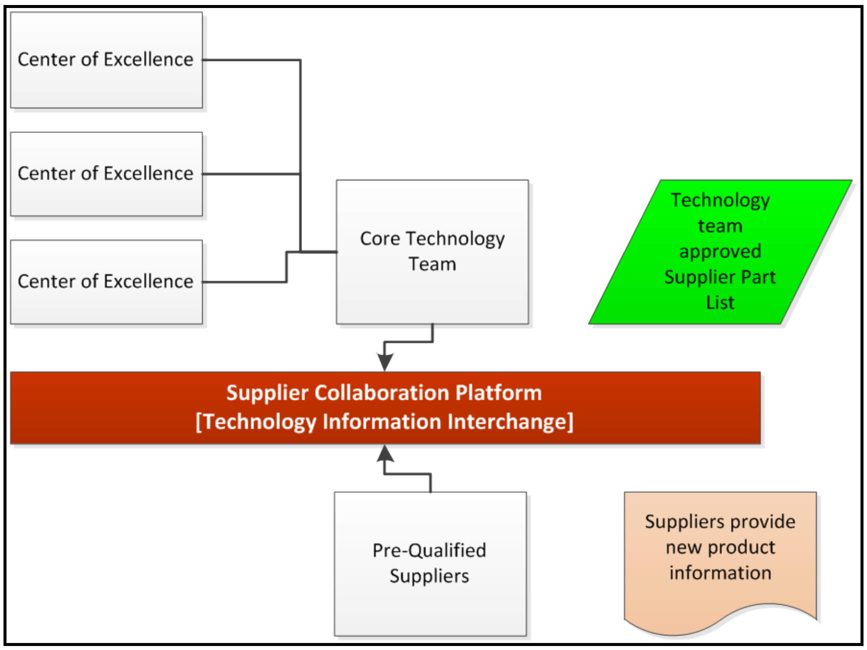

Fig – 3: Agility in design for integration of supplier's products in project execution

Having gained considerable experience through large-scale project execution, local business units are designated as Centers of Excellence for one or more business domains. This kind of experienced collaboration, between the Core Technology Team and the Centers of Excellence brings regional project execution experience to the global platform.

For project specific requirements - design agility is achieved by starting with generic designs based on previous project experience and feedback from suppliers. A template format for selections is create to include:

- Engineering metrics like equipment topology
- Environmental requirements such as altitude and operating temperature
- Electrical ratings

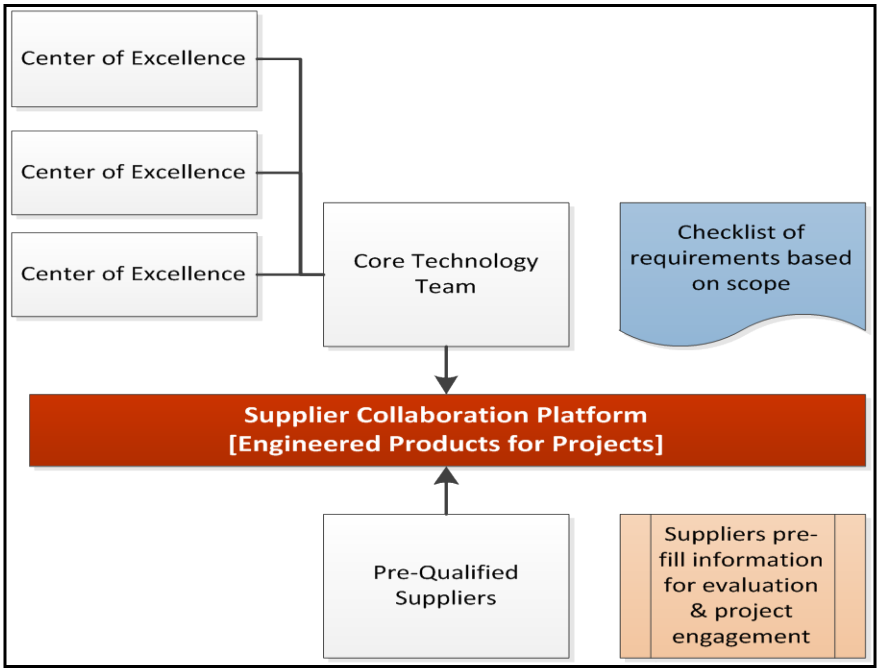

Fig – 4: Agility in design for project specific engineered products

Product Standards are developed keeping in mind the challenges being faced in various project scenarios. Participation in global standard development forums brings an in-depth understanding of the requirements; the technology forecasted by industry becomes visible to the organization. This vital information is fed back to global Core Technology Team members to ensure the product or service selection metrics are updated accordingly.

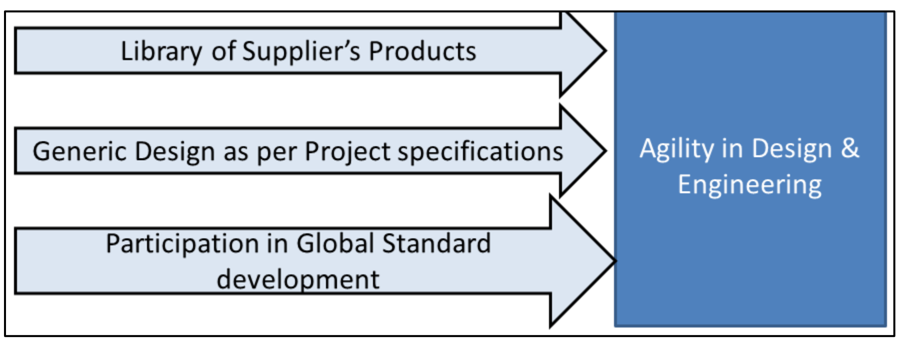

Fig – 5: Key Steps to achieve Agility in design and engineering

2. Collaboration with suppliers to achieve best system solution

Continuous market research ensures right supplier identification; product evaluation methods, potential certification details as well as price benchmarks are gathered.

Engagement with the potential suppliers identified by the market research is initiated by requesting equivalent product details from the suppliers of the parts which are currently being used in various projects. The equivalent product details provided are evaluated by the Core Technology Team before considering an update in the library.

By sharing typical project specific requirements for generic design creation, similar collaboration exists with suppliers. To mitigate unforeseen project demands throughout the project execution, suppliers are engaged consistently to identify the correct product or service for the application.

The logistics of the product and its installation in various new geographies requires varied levels of expertise. Suppliers are also employed to understand their extended business model and partnership with local organizations to expand these services.

Transparency in the collaboration methodology is ensured by using an e-Sourcing platform, which is successfully utilized with suppliers of both products and services. In large global organizations with a single format it becomes easier to retrieve and interpret data. Price visibility is achieved with multiple suppliers providing pricing information for products or services having the same set of specifications through a pre-defined cost-breakdown structure.

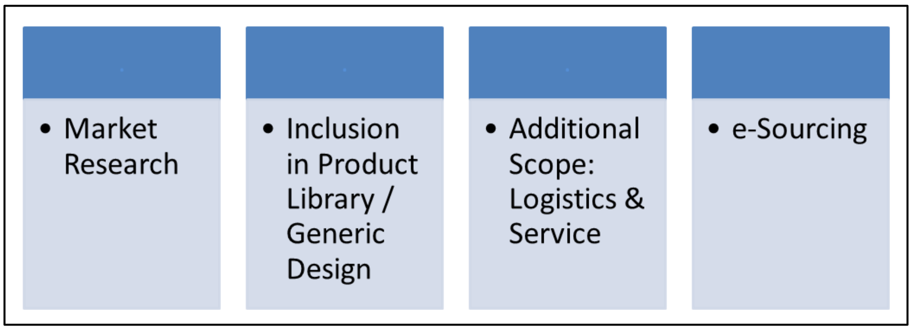

Fig – 6: Collaboration with Suppliers

As a proposed model, a supplier collaboration platform is being researched in which organizations provide access rights to suppliers to log-in and ensure their available product information is up-to-date. Suppliers can also be authorized to make changes in the technical or pricing data which flags the organization's internal team to ensure the updates are reviewed and any clarification required can be sought from the suppliers before releasing the information internally.

3. Supply chain risk reviews

Health and safety risk assessment and ways to mitigate potential risks in the supply chain are evaluated prior to any project engagement. Similarly, to ensure that all suppliers engaged in the project mitigate any such risks verification is required of how suppliers ensure such possibilities are mitigated by their sub-suppliers. This is achieved mainly through external certification bodies who verify the relevant processes such as ISO 9001/14001, OHSAS 18001.

Suppliers are requested to provide response in a questionnaire covering organizational information like financial history, organization structure and details of previous projects. The questionnaire also covers areas like sustainability, product and process design, operational excellence and costing methodology.

Details received from suppliers are referenced whilst conducting a supplier audit of the business locations to be used in the project. Experience from previous projects, ability to engage in multiple geographies and preparedness to provide qualification or test services are also evaluated during these assessments.

External organizations provide rating services for suppliers based on third party audits conducted. These scores can also be taken into account in addition to the internal assessments conducted on suppliers [15].

Projects under execution have a prolonged life, typically between 18 and 24 months, hence the periodic review of the regulatory and economic environment. This may result in modification of the project milestones agreed with the suppliers, resulting in changes in the supply chain.

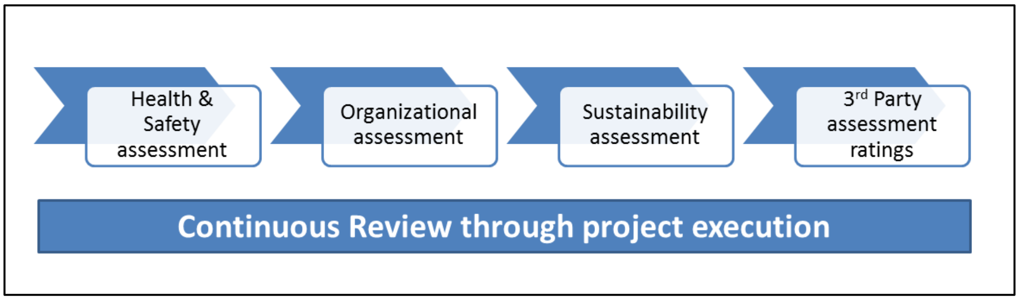

Fig – 7: Supply chain risk reviews

Summary - Achieving resilience in supply chain

Advanced preparation of generic design and engineering, with close collaboration with suppliers has proven to be invaluable to organizations during project executions. Modularity in design has brought in immense flexibility to organizations, speeding up the projects, as well as de-risking solutions by ensuring engagement of right expertise [13]. On the other hand, modularity also brings in disconnect between systems. If there is inadequacy in the design definition, the system interconnections can become a challenge resulting in non-workable systems. Centers of Excellence bring in the invaluable experience of managing multiple complex modules to provide a complete workable solution beyond the customer’s expectations.

Large scale systems integrator generates experience from multiple geographies conforming to different regulatory and certification requirements. With predefined supply chain management frameworks, established tools and supplier partnerships, challenges to project delivery becomes significantly reduced.

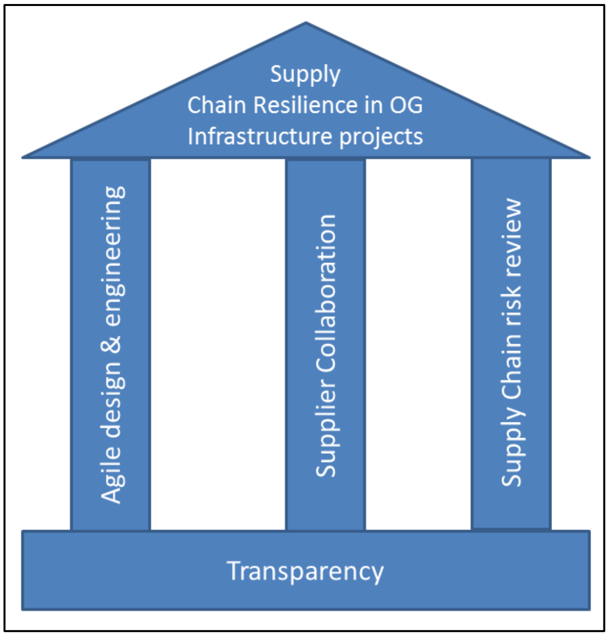

Fig – 8: Supply Chain Resilience in Oil and Gas Infrastructure projects

Conclusion and further research areas:

With the growing demand resulting in continued investment in the Oil and Gas industry, the challenges identified needs to be consistently revisited. Elements of Supply Chain Resilience bring in this framework.

The Core Technology Team of experts creates the critical organizational knowledge bank from various ongoing or executed projects from different geographies. This team, through participation in the standards development forum, brings industry forecasts to the organization.

Collaboration with Suppliers, to create an internal library of parts or generic design, for use in potential projects, results in agility in design and engineering. Electronic sourcing ensures transparency through information uniformity among the suppliers and the organization.

Supply Chain risk review can help to ensure health and safety for all stake-holders through internal and external due diligence reviews of the supplier's processes.

Overall, to achieve sustainable growth by making a conscious effort in risk reduction, organizations benefit through the key elements of Supply Chain Resilience.

Next level of supplier collaboration is being explored where internal organizational social media platforms are being considered for participation of key suppliers as well. It is expected that internal and external experts can share interests more openly, get advice as required, gain visibility in what's happening where and communicate in real time. [14]

Our research continues to explore the preparedness of the established supply chain frame-work. We would also like to focus on an implementation model between centralized Core Technology teams and distributed Centers of Excellence. We believe this creates a valuable pool of knowledge across geographies which can be utilized within the organization to achieve high efficiency.

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Greening manufacturing supply chains in Asia's emerging economies: A conceptual framework

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Abstract

In recent decades, rapid industrial modernisation and economic growth have brought substantial environmental problems for the Asian emerging economies; particularly China, Taiwan, India, Malaysia, Indonesia, Thailand and South Korea. As a result, the manufacturing sector in these countries has suffered negative environmental impact such as air pollution, waste and water pollution. Green supply chain management (GSCM) aims at reducing environmental impact while achieving economic, operational, social and environmental benefits. Based on a systematic literature review, this study has developed a conceptual framework and propositions for greening manufacturing supply chains in Asia's emerging economies. This study has identified areas for future research to raise the understanding of issues surrounding implementation of GSCM in this region. Moreover, the outcomes of this study are likely to guide manufacturing companies in other countries with comparable level of economic development to enhance sustainability of their operations and to green their supply chain.

Keywords: green supply chain management, Asian emerging economies, practices, performance

1. Introduction

Nowadays, most of the world's manufacturing operations facilities are located in Asia's emerging economies; particularly in China, Taiwan, India, Malaysia, Indonesia, Thailand and South Korea. The environmental burden has become a driver for environmentally friendly practices (Zhu et al., 2012; Lai and Wong, 2012). The majority of products consumed in developed countries have their resources or part of the manufacturing processes served by developing countries which are contributing to the world's economic growth (Lai and Wong, 2012). Over the past decade, green supply chain management (GSCM) has emerged as a significant environmental strategy within the domain of sustainability, which involves the management of the whole supply chain with suppliers and customers (Walker and Jones, 2012). In particular, according to Zhu and Sarkis (2004), GSCM refers to the comprehensive environmental consideration of supply chain management, which incorporates the design of product, the selection and sourcing of material, the process of manufacturing, the final product delivery to customer and the recycling after the useful life of a product.

The transition from traditional supply chain to GSCM has been influenced by many drivers which motivate manufacturers to adopt GSCM practices. Meanwhile, there are barriers that hinder the implementation of the GSCM practices (Porter and Vander Lindde, 1995; Gonzonez-Torre et al., 2010). Companies implement GSCM practices to achieve better supply chain performance (Zhu et al., 2007). Supply chain performance in this study is comprised of economic, environmental, operational and social performance.

In the past few years, there has been a growing interest in exploring the balance between environmental damage and economic growth by adopting the GSCM practices. A number of researchers have studied GSCM in Asia's emerging economies, including the influential factors and its relationship with supply chain performance. However, there is a lack of theoretical models for conceptualising, defining, modelling and testing of hypotheses. Many researchers argued that the GSCM in developing economies are still in the developmental stage where there is a need to theoretical base studies to link academic findings with industrial practices (Zhu, Sarkis & Geng 2005; Linton, Klassen & Jayaraman, 2007; Mohanty & Prakash, 2013). There is a need to summarise and integrate different results from existing literature and to develop a conceptual framework to examine the factors affecting adoption of GSCM practices and their impact on supply chain performance as well as identify managerial implications for further research (Mitra and Datta, 2014; Lo, 2014; Subramanian, 2014). This study aims to respond to this need by developing a conceptual framework followed by a number of hypotheses to green the supply chain in Asia's emerging economies through a systematic literature review.

2. Methodology

We have adopted a systematic approach to reviewing the literature (Tranfield, Denyer and Smart, 2003) for this study. We searched five well-known databases including: ABI/INFORM, Scopus, Emerald, Business Source Premier and Science Direct. These databases index the dominant majority of academic literature in operations management. They have had high numbers of hit rates for relevant literature of GSCM across multiple disciplines, which was the key consideration of this review. As shown in Table 1, in order to avoid artificial limitations and undesirable results, the selection of keywords was sufficiently broad.

Table 1. The key words used for searching papers

AND				
Region/Country	OR			
	Influential factors	GSCM practices		Outcomes
		AND		
China	driver	green	practice*	performance
India	enabler	sustainab*	activities	outcome
Thailand	pressure	environment*	operation*	advantage
Malaysia	influence		logistic*	
South Korea	barrier		production	
Indonesia			manuafacuring	
Taiwan				

The rest of the paper is organised as follows. Section 3 presents GSCM in Asia's emerging economies with practices in place, influential factors affecting GSCM adoption and the effect such as supply chain performance. Section 4 discusses hypotheses development drawing on the institutional theory and the resources based view that drivers the adoption of firm's GSCM practices and the proactive strategy mediating between those two drivers and the adoption; the industry specific barriers that hinder the adoption of GSCM practices; and the independent and collaborative practices effects on the environmental, economies, operational and social performance. Finally, the implication for both research and managerial, the conclusion with suggestions for further research provides in section 5.

3. **GSCM in Asia's emerging economies**

Emerging economies in Asia have had a rapid economic development over a short period of less than two decades (Hsu et al., 2013). However, the downside to this is a host of environmental pollution problems which are now of serious public concern. In order to develop an appropriate framework of greening the supply chain in that region, this section is divided into three parts: the adoption of GSCM practices, the factors that influence adoption of GSCM practices, including drivers and barriers and the impact of GSCM practices on performance.

3.1 GSCM practices

We found that most of papers that investigated the adoption of practices used the same measurement index developed by Zhu and Sarkis (2004) and Zhu et al. (2005). Zhu and Sarkis (2004) collected data from 186 respondents in Chinese manufacturing enterprises and identified four types of GSCM practices. These include internal environmental management, external environmental management, investment recovery and eco-design. Zhu et al. (2005) investigated Chinese textile, automobile, power generation, chemical, electrical and the electronics industries and further split external environmental management (Zhu and Sarkis, 2004) into green purchasing and cooperation with customers. Those five practices: internal environmental management, green purchasing, cooperation with customers, investment recovery and eco-design have widely used by researchers to measure the adoption of GSCM practices and their relationship with performance in manufacturing sectors in Malaysia, Thailand, India and Korea (Ninlawan, et al., 2010; Liu et al., 2012; Huang, Tan &Ding, 2012; Lee et al., 2013; Hajikhani, wahat & Bin, 2012). The adoptions of GSCM by large-sized companies and SMEs have slight difference. For instance, compared with the importance of direct cooperation with customers and suppliers in large-sized companies, SMEs prefer to adopt practices that can be managed independently such as setting supplier evaluation criteria.

As discussed in the above section that the GSCM practices have adopted by manufacturing companies in Asia's emerging economies but the extent and mode of implementation vary significantly. Previous studies in Asian have widely classified the adoption of GSCM practices into internal and external categories. However, in order to have a better understanding on the voluntary adoption of GSCM practices, we classified the GSCM practices into two categories: independent and collaborative. The independent GSCM practices concern the activities related with internal environmental management, eco-design, evaluation and selection suppliers and investment recovery that focal companies can implement and manage independently. Collaborative GSCM practices on the other hand refer to those activities that require direct collaboration with suppliers and customers including green purchasing, customer cooperation, supplier integration and reverse logistics. Moreover, similar classifications have been used in previous studies (e.g. Large and Gimenez Thomsen, 2011).

3.2 Influential factors on the adoption of GSCM practices

Following González-Torre et al. (2010), this study distinguishes between drivers and barriers. A driver is a factor that initiates and motivates firms to adopt GSCM practices, whereas a barrier is a factor that hinders the implementation of GSCM. Distinguish between drivers and barriers are essential because manufacturers have drivers to implement GSCM practices but barriers also exist that may affects the successful adoption of GSCM practices (Zhu et al., 2013). González-Torre et al. (2010) stated in order to obtain greater results of the adoption that many companies have started consider the barriers confronted when prepare to adopt GSCM practices. Another reason for the importance of investigating barriers is that most research in this field has been only focused on drivers. Therefore, identify barriers will help make better understanding of the adoption of GSCM practice.

Drivers

We classified drivers based on the institutional theory and resource-based view. This classification maybe most appropriate for explicating the effect of the drivers for GSCM and how they might influence specific adoption of GSCM practices. Based on the institutional theory, we assume that the GSCM can be motivated by three kinds of drivers: coercive, normative and mimetic (DiMaggio and Powell, 1983). The coercive drivers concern the influences of power such as government agencies that can affect the actions of companies (Zhu et al., 2013). The increased environment awareness in governments results in legal requirements, regulations and policies that force and motivate adoption of GSCM practices. Normative drivers are the pressure from different external stakeholders which cause companies to adopt GSCM practices in order to be perceived as having legitimate activities (Zhu et al., 2013). Finally, mimetic divers encourage organisations to learn from the successful competitors and professional groups in the same industry (Lee and Klassen, 2008; Lee et al., 2013).In addition, resource-based view applied to GSCM can be achieved through resources that are valuable, rare and inimitable (Delmas and Toffel, 2004). For instance, the internal factors from organisation itself that helps the company implement GSCM including the support from manager, the mission statement for being environmentally friendly and the training program for employee. The drivers of large-sized companies and SMEs for the adoption of GSCM practices are different. The reviewed literature showed that the employees training programme and green strategy are not considered as major influential factors in large-sized companies but have significant impact on SMEs. This may be due to the fact that SMEs usually lack the information, resources, or expertise to deal with environmental issues (Lee, 2008). Therefore, SMEs need support from external stakeholder such as upstream-supplies to bringing new concept into the technical and managerial changes to meet the environmental requirements (Lin and Ho, 2011).

Barriers

According to Post & Altma (1994), barriers are the factors that hinder the implementation of GSCM. Based on the reviewed literature, this study grouped the barriers into two categories: industry specific barriers and organisational barriers. The industry specific barriers are related to external factors such as industry characteristics, the deficient industrial infrastructure and the pressures from regulation (González-Torre et al., 2010). The GSCM may lead managers to justify those practices that are difficult to implement and give priority to other practices which may have more visible financial return on investment (Zilahy, 2004). Organisational barriers are fundamental obstacles to the adoption of GSCM practices (Abdulrahman et al., 2014). For instance, to introduce a new technology, an organisation needs staff to facilitate adaptation to the new technological process (González-Torre et al., 2010). This discourages companies to make a change in the manufacturing process and ways of organising work, and leads to inertia in companies' routines hindering both internal and external communication and impeding the transmission of commitment to GSCM at all levels of the company (Zilahy, 2004).

3.3 The supply chain performance

Based on the reviewed literature, one of the most important issues related to GSCM is to examine the relationship between the adoption of GSCM practices and supply chain performance. In this perspective, companies that implement GSCM practices aim to achieve better supply chain performance (Zhu et al., 2007). The reviewed literature has focused on the adoption of GSCM practices in relation to environmental, operational, social and economic performance. The environmental performance is usually concerned with saving energy and reducing waste, pollution and emissions. The operational performance is related to the efficiency of the firm's operations with indicators such as scrap rate, delivery time, inventory levels and capacity utilisation (Zhu et al., 2005). The social performances in this study are composed of social sustainability and corporate social responsibility (Zailani et al., 2012; Ashby, 2012). Finally, economic performance is concerned with financial indicators such as sales and market shares (Lee et al., 2013).

4. Hypothesis and conceptual framework development

4．1 Drivers based on the institutional theory

As discussed in the above section, regulations are defined as the key coercive driver which can be classified into domestic environment regulations and international acceptance. Some researchers argued that Asian emerging economies are still in the process of setting up such domestic environment regulations. Thus, the primary drivers are the international acceptances which caused firms adopted GSCM practices to re-evaluate their investment recovery and reclamation programs (ElTayeb, Zailani & Jayaraman, 2010; Zhu, Sarkis & Lai, 2011). In contrast, the reviewed papers show that domestic regulations seem to be more powerful to encourage GSCM adoption compared to international acceptance in Asian emerging economies (Miao, Cai& Xu, 2012; Wu, Ding& Chen, 2012; Mohanty and Prakash, 2013). In this perspective, Zhu et al. (2013) have demonstrated that domestics regulations set by the Chinese central government about industrial pollution from 2010 has become a more powerful driving force compared with international acceptances of the adoption of GSSCM practices for Chinese manufacturing companies. For example, China is the first country that adopted both Cleaner Production Promotion Law and Circular Economy Promotion Law on 2010 (Huang, 2012). These two laws are the standardized policy to dealing with the huge size and diversity in different regions (Mol and Carter, 2006). This statement is in line with Wong and Lai (2012) that indicated manufacturers in Asia's emerging economies have experienced more pressures from domestic environmental protection regulations than before.

As one of the major factors in normative driver, customers can put significant pressure and demand sustainability and/or environmental performance from suppliers (ElTayeb et al., 2010). The reviewed papers showed that manufacturers who dealing with customers from western countries have more direct to meet social consumer expectations and norms in Asian merging economies (Lin and Ho, 2011;Hajikhani, wahat & Bin, 2012;Miao, Cai& Xu, 2012;Subramanian,2014). In this perspective, the requirements from international customers particularly from western countries for green products have become one of the most significant factors that force companies to adopt GSCM practices. Moreover, according to Lee et al. (2013) community stakeholders are not essentially included in the partnership with companies but they have familiarity with the community. For example, some NGOs in those regions have started to promote the concept of industrial ecology by recovering all the waste through proper recycling and reuse (Hsu et al., 2013).

Finally, in terms of mimetic divers, the internationalization has created good chance for Asian manufacturers to learn from and share innovations with their foreign competitors, especially for those foreign companies who are operating in the same region (Liu and Buck, 2007). For instance, a number of empirical studies found that due to the long experience of international business exposure through exporting products to multinational companies, the electrical/electronics industry seems to have better environmental management practices in China, Korea and Malaysia (Zhu and Sarkis, 2006; Ninlawan, et al., 2010; Hsu et al., 2013). In this regards, joint ventures in Asia's emerging economies can implement GSCM practices for goals of saving energy and improving supply chain performance by learning from their parent companies in developed countries, and then diffuse experiences to other manufacturers (Mohanty and Prakash， 2013).

Based on the above arguments, the hypothesis is developed as follows:

H1a. The drivers based on the institutional theory have a positive influence on the adoption of GSCM practices of manufacturing companies in Asia's emerging economies.

4．2 Drivers based on the resource-based view

The resource-based view of the firm investigates strategies in companies with internal resources and capabilities (Delmas and Toffel, 2004). In this study, the drivers of resource-based view are internal factors from organisation itself that help the company implement GSCM including the support from manager, the mission statement for environmental friendly and the training program for employees. The reviewed literature showed a significant positive relationship from management support and environmental mission statement with the adoption of GSCM practices. However, training program for employees has received less attention. According to Mohanty and Prakash (2013), the capacity for the adoption of GSCM practices is usually enhanced by professional educated and trained employees. Therefore, those factors based on resource based view may be essential because green behaviour needs collaboration and coordination from different sectors and functions crossing the companies during adoption. In addition, from the GSCM perspective, resource-based view can improve competitive abilities to continuously innovate and develop new products and services (Dodgson et al., 2008). These abilities allow companies to respond to market actions (Zhu et al., 2007). Given these initial arguments, the next hypothesis is developed as follows:

H2a. Drivers based on the resource-based view of the firm have a positive influence on the adoption of GSCM practices by manufacturing companies in Asia's emerging economies.

4.3 The moderating role of proactive strategy

The relevant literature shows the importance of the awareness and attitude of companies to going green. For instance, Walton et al. (1998) proposed six strategies that companies might take into account when they decide to going sustainable include resistant adaptation, embracing without innovating, reactive, receptive, constructive, and proactive. Afterwards, Van Hoek (1999) grouped these six strategies into two categories: reactive and proactive. For company who processing with a reactive attitude that they response to GSCM practice only in a necessary situation and in the most basic manner to comply with legislation. In contrast, a company with proactive strategy, GSCM practices is value-added practices and they associates with all business customers and suppliers to create the advantages for the supply chain. Moreover, the reviewed papers also suggested that in order to towards the competitiveness in global market, manufacturers in Asian emerging economies should assume a more proactive and responsible strategy (Rao 2002; Zhu and Sarkis 2004; Zhu, Sarkis, and Geng, 2005). In this perspective, companies with proactive strategy usually have higher level of adoption of GSCM practices beyond requirements of laws and regulations, while reactive strategy only seek compliance with regulatory requirements. In addition, Zhu et al. (2007a, 2007b, 2012) and Wu et al. (2013) argued that companies with proactive strategy to the adoption of GSCM practices of their products and services may have the chance to get better operational performance in emerging economies.

The environmental strategies used by leading companies were chosen based on the requirements of the institutional environment (Chiou, et al., 2011). When companies facing the institutional pressure, the stakeholders may force companies to implement proactive strategy to adjust operation and reallocate their resources (Sharma & Vredenburg, 1998). In contrast, companies may not allocate their resources for environmental without the institutional pressure. In a word, with the intense environmental intuitional pressures, firms would adopt proactive environmental strategy to implement more comprehensive GSCM practices in order to maintain a competitive advantage (Chan et al., 2012).

H1b. Proactive strategy moderates the relationship between the institutional drivers and the adoption of GSCM practices.

In terms of the resource-based view, the strategic actions of resources could yield new organisational thought and develop dynamic capabilities, which forced companies to keep readjusting their resource allocation (Eisenhardt and Martin, 2000; Chan et al., 2012). In this perspective, Darnall and Edwards (2006) argued that the drivers from resources such as valuable, rare and inimitable would help companies in adopting proactive environmental strategy and in dedicating themselves to more comprehensive environmental practices. Given these initial arguments, the following hypotheses are developed:

H2b. Proactive strategy moderates the relationship between the resource-based view drivers and the adoption of GSCM practices.

4.4 Industry specific barriers for the adoption of GSCM practices

According to Del-Brío and Junquera (2003), the costs of environmental adoptions were one of the external industry-specific barriers. The GSCM may lead managers to justify those practices that are difficult to implement and give priority to other practices which may have more visible financial return on investment (Zilahy, 2004). In line with this argument, there is also a question that as the measures are easily imitated weather these GSCM practices can be determine value properly by customer and contribute to the competitive advantage as well as finical performance (González - Torre et al., 2010). Moreover, another external industry-specific key barrier is the deficient industrial infrastructure (Porter and Van der Linde, 1995). As many industries relay on separate infrastructures for GSCM, it requires deep investment that result in unwillingness of companies to invest in their own operations (Seitz and Wells, 2006). In this respect, Abdulrahman, Gunasekaran and Subramanian (2014) argue that due to the limited capacity to build relations with servicers sectors and external organisations, this barrier is the major factors that hinder the adoption of GSCM for SMEs in Asian emerging economies. Given these initial arguments, a hypothesis is developed as follows:

H3. Industry specific barriers have a negative impact on the GSCM adoption of manufacturing companies in Asia's emerging economies.

4.5 The adoption of GSCM practices and supply chain performance

Although the priority goal for Asian merging economies is economic development, the increasing global focus on the environmental issues has enquired the manufacturing sector in this region to have positive response towards improving the environmental outcome (Lee, 2013; Mohanty and Prakash, 2013). In response to these issues, governments in Asian emerging economies have been establishing stricter environmental regulations in order to improve environmental performance (Zhu, Sarkis& Lai, 2013; Wu 2013; Lo, 2014; Mathiyazhagan, Govindan & Haq, 2014). In addition, researches on GSCM in Asia's emerging economies have mainly focused on economic, operational and environmental performance. However, some social issues such as product safety and labour conditions have become more significant. Consequently, social performance has also become a key element to greening the supply chain (Gimenez and Tachizawa, 2012). This section is explores the adoption of independent and/or collaboration GSCM practices in relation to companies' environmental, operational, social and economic performance.

Lai and Wong (2012), Lai, Wong and Cheng (2012) and Dou et al. (2013) have found the positive influence of the adoption of independent practices on environmental performance. Moreover, Chiou et al. (2011) have also demonstrated that greening the supply chain by independent GSCM practices had a positive association with environmental performance but one of the construct of GSCM practices was not related to the environmental performance. In particular, Chiou (2012) provided three kinds of independent GSCM practices including product innovation, process innovation and managerial innovation. Among those three practices, the green managerial innovations have found no relationship with environmental performance. In addition, there were two studies (Chiou et al.,2011 and Dou, et al.,2013) that have found a positive the relationship between the suppliers selection and supply chain performance with environmental and operational performance. Moreover, Kuei et al. (2013) focused on independent environmental management whilst Lai, Wong and Cheng (2012) considered the investment recovery and found a positive impact on economic performance. Given these initial arguments, the following hypotheses are developed:

H4a: The adoptions of independent GSCM practices have a positive impact on companies' environmental performance.

H4b: The adoptions of independent GSCM practices have a positive impact on companies' economic performance.

H4c: The adoptions of independent GSCM practices have a positive impact on companies' operational performance.

In terms of the adoption of collaborative GSCM practices, Mitra and Datta, (2014) and Abdullah and Yaakub, (2014) investigated reverse logistics practices and found that manufacturers have not assumed a proactive role to consider these practices in the design phase. This may indicate that manufacturers in Asian emerging economies are not really ready to commit themselves towards investing and allocating extra resources for reverse logistics adoption. Moreover, both studies found no support for environmental performance. The reasons could be explained based on the theory of transaction cost economics, which suggests that the cost of collaboration with customers and suppliers in arms–length relationships is higher than that of independent practices within the companies (Carter and Rogers, 2008). In contrast, Zhu, Sarkis and Lai (2011) and Zailani et al. (2012) considered collaborative GSCM practices and found support for a positive impact on environmental and operational performance. Zhu, Sarkis and Lai (2011) considered the adoption of green purchasing and customer cooperation practices and collected data from 377 manufacturing companies. They found that greater cooperation and coordination with suppliers and customers through long-term and strategic relationships have positive impact on economic, environmental and operational performance. However, they argued that Chinese manufacturing with international exposure have better economic performance than those with a domestic focus. The reason may be due to the international customers that have higher requirement on environmental production and products (Lee et al., 2013). In particular, Chinese manufacturers adopt GSCM practices as a response to the increased international pressures, and that these practices can be helpful for them to reap performance gains on environmental, economic and operational dimensions (Zailani et al., 2012). Hence, the following hypotheses are developed:

H5a: The adoptions of collaborative GSCM practices have a positive impact on companies' environmental performance.

H5b: The adoptions of collaborative GSCM practices have a positive impact on companies' economic performance.

H5c: The adoptions of collaborative GSCM practices have a positive impact on companies' operational performance.

In terms of social performance, Zailani et al., (2012) collected and analysed data of 400 manufacturing firms in Malaysia on environmental, economic, operational and social performance. To the best of our knowledge, this is the only paper that mentioned the impact of GSCM on social performance. They found that the adoption of green purchasing and green packaging, as two collaborative practices, have a positive effect on social performance. This finding was in line with Preuss (2000) who showed that the implementation of social and/or environmental standards could be transferred to suppliers by the purchasing function. This can generate a chain effect leading to quick and deep changes in overall social outcomes (Zailani et al., 2012). In particular, manufacturing sectors in Asia's emerging economies were relatively primitive and tending to beat their competitors through cheap labour and producing large amounts of goods (Zhu, Sarkis and Lai, 2011; Lo, 2014). For example, Foxconn is a major manufacturer in China catering to Apple, Dell, HP, Motorola, Nintendo, Nokia, and Sony. Fourteen employees of the company attempted suicide between January and November 2010 due to poor working conditions (Chan, 2013). Therefore, social performance could be considered as an important factor to make supply chain truly sustainable. Hence the following hypotheses are proposed:

H4d: The adoptions of independent GSCM practices have a positive impact on companies' social performance.

H5d: The adoptions of collaborative GSCM practices have positive association with companies' socially performance.

4.6 The mediating role of supply chain performance

The pervious research on the adoption of GSCM and economic performance seems to have less acceptance level. For example, Zhu and Sarkis (2004) and Zhu et al. (2005) found GSCM practices have only improved environmental and/or operational performance, but not resulted in a significant economic performance. Admittedly, the concept of GSCM practices were in its early satge at the time of these two studies and most of the Chinese companies have only implementated limited numbers of GSCM practices. The early stage of adoption usually requires investment which will increase companies opearational costs and have a negative impact on firms' economic benefit. Meamwhlie, Zhu, Sarkis & Lai (2013) found there was no direct improvement between GSCM practices and economic performance. However, they have shown that although the GSCM practices does not affect economic performance signifacantlly, but the relationship could be moderated by improved enviromental and operational performance in longer term. This result is in line with Lee, Kim and Choi (2012) who found that economic performance can be enhanced through the achievement of operational efficiency after a company adopts GSCM practices. For instance, the adoption of GSCM practices might increase efficiency of processes and recycling of wastes, avoidance of penalties, disposal costs and higher future costs of compliance (Lee, Kim and Choi, 2012). Consequently, those practices could improve economic performance by improving operational performance. Similar results were drived from the study of Lee et al. (2013), who found that GSCM practices can increase supply chain flexibility which allows organisations to save costs from the resource aspect such as increased scrap rate, delivery time and reduced inventory levels and hence enhances economic performance. Moreover, Zhu, Geng & Lai (2011) and Ninlawan et al. (2011) have provided the support for positive impact on the economic perforamnce by improved enviromental performance. In this perspective, the adoption of GSCM practices could improve companies' image, increase market share, creates new market opportunities, and thereby leads to improved economic performance. Given these initial arguments, the following hypotheses are developed:

H6a: The impact of the adoption of independent GSCM practices on companies' economic performance is mediated by environmental performance.

H6b: The impact of the adoption of independent GSCM practices on companies' economic performance is mediated by operational performance.

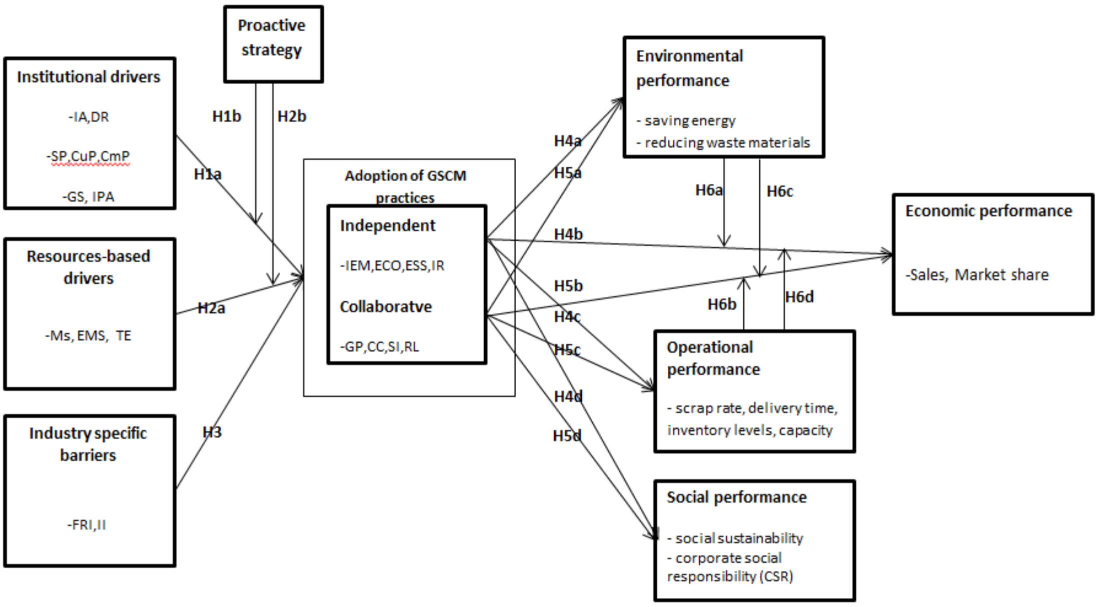
H6c: The impact of the adoption of collaborative GSCM practices on companies' economic performance is mediated by environmental performance.

H6d: The impact of the adoption of collaborative GSCM practices on companies' economic performance is mediated by operational performance.

4.7. The conceptual framework

The above hypotheses are integrated in a conceptual framework which is shown in Figure 1. It shows the crucial relationships among all significant dimensions of GSCM in Asian emerging economies.

Figure 1. The conceptual framework to greening manufacturing supply chains in Asian's emerging economies



IA: International acceptances; **DR:** Domestic regulation; **SP:** Suppliers pressures; **Cup:** Customers pressures; **CmP:** Community pressures; **GS:** Green strategy; **IPA:** Industry professional group activities; **MS:** Management support; **EMS:** Environmental mission statement; **TE:** Training employees; **FRI:** Financial return on investment ; **II:** Industrial infrastructure ; **IEM:**Internal environmental management; **ECO**: Eco-design; **ESS:** Evaluate and select suppliers; **IR:** Investment recovery; **GP**: Green purchasing; **CC:** Customer cooperation; **SI**: Supplier integrations; **RL**: Reverse Logistics

5. Implication and conclusion

This study developed lists of hypotheses on the positive relationship between the adoption of GSCM practices and the environmental, operational, economic performance and social performance. Moreover, this study also provides manufacturers with the insights on what drivers/hinders the adoption of GSCM practices. From this understanding, manufacturers may rewrite their environmental policy and strategy based on the influential factors on the adoption of GSCM. For instance, the internal environmental management provide some practical implication such as set down environmental missions and on-the-job training which will help companies to adopt GSCM practice easily. In addition, the outcomes of this study could guide manufacturing companies in Asia's emerging economies in enhancing sustainability of their operations and greening their supply chain. Due to growing awareness in the developed countries about environmental sustainability, companies in Asia's emerging economies recognise and implement the concepts of GSCM. This is essential for them to compete in the global market and satisfy their customers' increasing needs about environmental impact.

Moreover, through the development of a conceptual framework, this study also found several trend in the GSCM studies. Previous researches have primarily focused on large-sized, foreign-owned or state-owned companies. Therefore, the drivers for them were likely to be initiated by the government and large buying firms to facilitate involvement of suppliers in GSCM practices. However, a supply chain base as well as a country's industrial base might primarily consist of SMEs (Lee, 2013). Thus, the formation and development of industry chain and industry integration, GSCM of SMEs in Asian emerging economies has become an important factor in the market competition. Therefore, the phenomenon of the adoption of GSCM practices by SMEs could be treated as missing part in GSCM practices in Asian emerging economies. Further research could apply this framework in a SMEs perspective which might allow specific features to be recognised in greater detail. Moreover, further research could also improve this framework by taking a closer look on the relative effect of each of these influential factors that identified in this study on the different adoption of GSCM practices.

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International manufacturing networks: how changes at strategic level impact their design and management

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Abstract

This paper focuses on the dynamic relationship between corporate strategy and international manufacturing networks. It argues that multinational companies will only be able to change its strategic positioning if the configuration of its international manufacturing networks provides organizational support for such change. The object of study are emerging country multinationals which, due to its late entry in international markets, provide a privileged field for the research. The study reveals that there is a co-evolution between strategy and network design. Additionally, it is proposed a systematic corporate strategic process for emerging country multinationals in order to define one or a set of missions that will guide the design and management of their international manufacturing networks.

Keywords: International Operations Management, International Manufacturing Networks, Internationalization strategy, Emerging Country Multinationals.

1 – Introduction

International Manufacturing Networks (IMN) is gradually being consolidated as a stream of research in International Operations Management (IOM). After the pioneering works of Ferdows (1997) and Shi and Gregory (1998), a number of authors have contributed to address a range of related issues. For example, Miltenburg (2009) developed a framework that links IMN to corporate global manufacturing strategy, in a multinational company; also, Feldmann et al. (2013) studied what happened to a company's IMN configuration when one plant (one node in the network) has its strategic role changed, that is, it upgrades to more complex roles. However, lack of research on the interaction between the strategic level and the IMN remains. This paper seeks to fill this gap, by addressing the problem of how a changing corporate strategy affects the IMN, over a period of time.

The object of the study are emerging country multinationals (EMNEs). The rise of EMNEs, in the last 20 years, has created a privileged field for empirical research on IOM in general and production networks in particular. The reason is that they are newcomers in global markets and, consequently, are still experimenting new forms of organization, in contrast with the more mature – and "rigid" – worldviews and organizational models adopted by developed country multinationals (DMNEs). Furthermore, EMNE's internationalization patterns usually are different from DMNEs, because they suffer stronger influence of institutional factors

(Sethi and Elango, 1999), grow in the shade of Global Production Networks (GPN) led by DMNEs, rely on production and operations as key competence (Fleury and Fleury, 2011) and finally have to develop new configurations for their internal value networks (Srai, 2013) better suited for their fast-paced expansion (Mathews, 2006).

The complexity and dynamism of IOM should be addressed with new analytical frameworks, drawn on streams of research based on both Operations Management (OM) and International Business (IB). For this research, the framework developed by Fleury et al. (2012) is adapted in order focus on the strategic and network levels mainly. Moreover, the analysis should take into consideration the principles of strategic fit (Galbraith, 2000), which advocate that companies have to get themselves aligned both externally (with the business environment) and internally (within the organization). More particularly, the fit should enable the contribution of Operations function to the execution of the overall strategy, through the reconciliation of market requirements with operations resources (Slack and Lewis, 2002).

As this is an exploratory, longitudinal research, two illustrative case studies of Brazilian multinationals are used. Both have sophisticated IMNs and are largely connected to GPNs in their respective industries. Based on the empirical findings, an evolutionary map for those EMNEs is drawn, describing the relationships between the positioning in a GPN, the generic internationalization strategy and the network configuration for each strategy, over a period of 20 years.

2 - Literature review

The literature review considers three research streams: international manufacturing networks, corporate strategy implementation and generic internationalization strategies of EMNEs.

2.1. International manufacturing networks

The research developed at the Institute for Manufacturing, University of Cambridge, has been setting the agenda for IMN studies, a concept introduced by Shi and Gregory (1998). These authors expanded Hayes and Wheelwright's (1984) Factory Manufacturing System towards International Manufacturing Networks considering geographic dispersion, coordination mechanisms (both horizontal and vertical) and factory's characteristics as key levers for the network. The combinations of these levers result in seven types of network configurations, which in turn create four types of network capabilities (Figure 1).

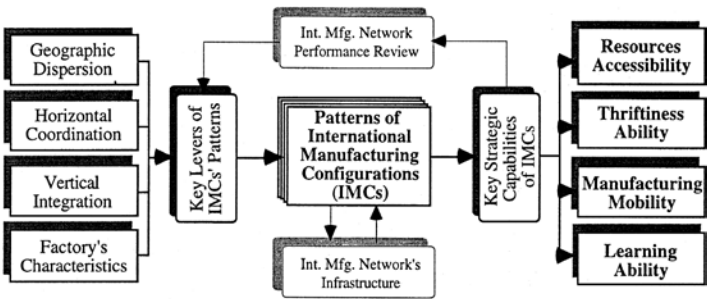

Figure 1 – Key capabilities derived from international manufacturing networks. Source: Shi and Gregory (1998).

Aiming at creating an integrative framework to describe and explain a multinational company's global manufacturing strategy, Miltenburg (2009) drew on Shi and Gregory's (1998). For Miltenburg (2009), the framework elements are manufacturing strategy's "objects" (generic international strategies, manufacturing networks, network manufacturing outputs, network levers, network capability, and factory types) which are related as in Figure 2. This framework extends Shi and Gregory's as it systematically seeks the relationship between the micro/operational level (factories), the meso/intermediate level (the manufacturing network) and the macro/strategic level (the company's manufacturing strategy). As Shi and Gregory (1998) propose that different configurations lead to different capabilities, Miltenburg (2009) adds that different configurations reflect different international manufacturing strategies.

Finally, Feldmann et al. (2013) drew on the previous frameworks to study changes in the international manufacturing network configuration when a subsidiary upgrades or downgrades its strategic role. Focusing on the relationship between the intermediate level (the network of subsidiaries) and the operational level (individual subsidiaries), the authors show that such shifts are likely to lead to systemic realignments within the company's IMN.

2.2. Generic internationalization strategies in EMNEs

As highlighted by authors like Peng, Wang and Jiang (2008), the internationalization of EMNEs is clearly influenced by the characteristics of the institutional environments where they were born. In addition, they usually grow as part of Global Production Networks (GPNs) led by developed country multinationals (DMNEs), what creates specific drivers and constraints for their international expansion. These two factors impact the formulation of strategies at firm level.

- *Country-of-origin effects*: derive from a combination of factor endowments, cultural traits, and policy options (Sethi and Elango, 1999). Three sets of elements: (1) both economic and physical resources and industrial capabilities, (2) cultural values and institutional norms, and (3) national government economic and industrial policies shape the propensity towards internationalization readiness and decisions. Resources and capabilities create drivers influencing firms' strategies. Among the BRIC countries, Brazil and Russia are rich in natural resources while China and India have large populations and few natural resources. That favors the development of nature-based companies in the former countries and assembling-type of industries in the latter. Values and norms are associated to the informal and formal institutions of a country. At the macro level, that reflects the business ecosystems where firms operate which can be more or less conducive to internationalization. At the micro level, organizational culture is heavily influenced by the nation's cultural environments. Depending on what types of values and norms prevail, organizations may lean towards entrepreneurship and risk-taking or conservatism and risk aversion. China and the India are considered nations which cultivate entrepreneurship while Brazil is said to be more conservative and risk-averse. Finally, governmental policies are clearly an important factor affecting emerging country firm's internationalization. For example, the international expansion of Chinese multinationals has been supported by the government through the 'Go Global' project, among other initiatives. Contrarily, both Brazilian and Indian institutions show conservative postures in regards to the importance of their firms moving abroad.

- *Global Production Networks*: usually emerging country firms engage in GPNs, what influences its propensity for internationalization and its entry strategy in international markets. Fleury and Fleury (2007) proposed the Competence-based Positioning Framework to analyze the influence of the link to a GPN with regard to the firm's strategic positioning. The authors admit that, in GPNs, firms occupy one of six different positions depending on their core competences: (a) Manufacturers (key competence is Production and Operations Management); (b) Developers (R&D); (c) Integrators (Systems Engineering); (d) Service Providers (Service Operations Management); (e) Logistics Providers (Logistics) and (f) Technology Suppliers (providers of specialized knowledge for industry). Evidently, their argument assumes that every firm must master the whole set of organizational competences but there are core competences that provide strategic leverage to the firm.

- *Generic strategies*: Ramamurti and Singh (2009), considering the influences of both country-of-origin effects and GPNs, observed that EMNEs are not a homogeneous group by any means and identified five generic internationalization strategies:

- Natural-resource vertical integrator – firms located in countries rich in natural resources and large demand for such inputs, which internationalize to achieve forward integration to downstream markets and/or backward integration upstream to secure natural resources;
- Local optimizer: firms located in countries populated by low-income consumers and underdeveloped 'hard' and 'soft' infrastructures which have the ability to reengineer imported products thus creating products suited for emerging markets;
- Low-cost partner: firms located in low-cost labor countries, where a large pool of skilled labor is available, which become global suppliers for GPNs and, simultaneously move up the value chain to increase value-adding and down the value chain to diversify supply locations;
- Global consolidator: firms located in large and rapidly growing home markets where customers are price sensitive, which achieve manufacturing excellence and move internationally to achieve global scale through the acquisition of poorly performing companies;
- Global first-mover: firms located in countries characterized by large and rapidly demand in a new industry where design, engineering and production are low-cost, which target the global market and internationalize to acquire key technologies or capabilities and customer access.

These generic strategies are the primary determinant of the mission statement for the network in the case of emerging country multinationals.

2.3. Analytical frameworks linking corporate strategy and IOM

There is a plethora of studies on operations strategy, but little on how changes in corporate strategy affect the production system (the IMN). In accordance with strategic fit principles, changes in strategy convey changes to the structure (Chandler, 1962; Galbraith, 2000). Usually, the most visible outcome of the strategic process for IOM is a set of strategic requirements (or missions) assigned to the IMN.

Once the corporate strategy is formulated, the mission for the IMN is then defined. This mission guides the dispersion of subsidiaries with specific roles (Ferdows, 1997), the governance and coordination mechanisms, as well as the establishment of flows (information, knowledge, materials, people, finance) among the subsidiaries. The IMN features result in a configuration, which creates capabilities that potentially contribute to the accomplishment of the missions (Shi and Gregory, 1998). The design elements are described as follows:

- Mission: Shi and Gregory (1998) present an operational approach to network mission by admitting that it may be: (1) Efficiency-oriented, when it seeks economies of scale/scope, international operations synergies, the leveraging of expertise or precious resources on a global scale, and the sharing and reuse of existing solutions; (2) Innovation-oriented when it leads to customer intimacy, technology leadership, and market/technology-driven innovation, learning across disciplines or organizations; or (3) Flexibility-oriented when it relies on flexible work approaches, mobile engineering resources, reconfigurable network structures, and local responsiveness.

- Geographic dispersion: Dispersion is usually drawn by forces external to the company, especially new market opportunities. There is a full range of options for dispersion. Shi and Gregory (1998) classify as Domestic those in which all production is carried out in a single country serving both home and export markets. Regional approaches refers to factories and networks located in a particular geographical region, usually sharing similar cultural value systems. Multinational approaches, with trans-regional dispersion, involve factories located in several countries or free-trade zones.

- Governance/coordination: Co-ordination refers to the question of how to link or integrate the production and distribution facilities in order to achieve the firms' strategic objectives or its network mission (Meijboom and Vos, 1997:790). Governance refers to the mechanisms to direct and control the network, including authority structures, performance measurement and coordination mechanisms. There can be two generic orientations: multidomestic (weak coordination and more independent factories) and global (strong coordination and more interdependent factories, from either designed system structures or operations processes).

- Operations Processes: Referring to the flow of material, information and knowledge between members in the network to create valuable output to customers. For Shi and Gregory (1998) and Zhang and Gregory (2011), the processes control the operational mechanisms. They are structural elements regarded as the dynamic levers of the manufacturing network, in opposition to the static levers such as geographic dispersion, coordination and the factories.

- Configuration: It is the combination of the elements previously described: geographic dispersion, governance, operations processes and subsidiary roles representing the potential contribution to the accomplishment of the corporate strategy. For Shi and Gregory (1998) seven possible configurations for an IMN emerge: Regional Uncoordinated (MMC1), Home Exporting (GMC1), Regional Exporting (GMC2), Multidomestic (MMC2), Glocalised (MMC3), Global-Integrated (GMC3) and Global-Coordinated (GMC4).

- Capabilities: The capabilities created by the IMN configuration are classified as Cost Efficiency, Customer Responsiveness, Resource Accessibility, Agility, Learning, Risk Management, and Manufacturing Mobility(Fleet and Shi, 2005; Srai and Gregory, 2008).

- Subsidiary role: Although this level is off-scope in the present study, it is noteworthy that each subsidiary has a strategic role within the intra-firm network. Ferdows' (1997) types of subsidiary roles (offshore, source, server, outpost, contributor, and lead) remain predominant in literature; each type demands distinct sets of competences. Rugman, Verbecke and Yuan's (2010) classify them as Production, Innovation, Marketing and Administrative competences.

Figure 2 shows the IOM framework (Fleury et al., 2012), upon which the fieldwork will be based.

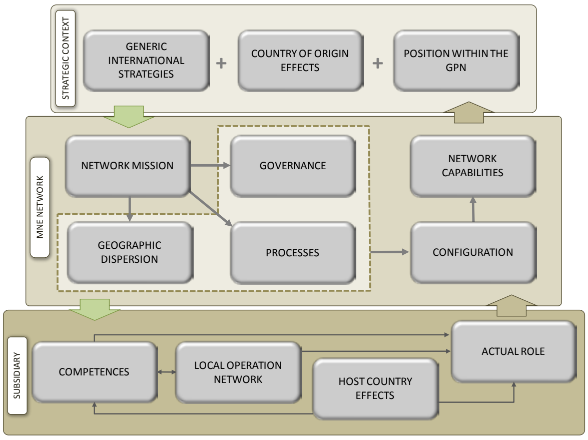

Figure 2 – Relationship between strategic context and the network of subsidiaries. Source: Fleury et al. (2012).

3 – Research Proposition

The literature review showed that there is a gap between the literature on IMN reconfiguration and corporate strategy, despite the contributions of Shi and Gregory (1998) and Miltenburg (2009).One of the hypotheses for that scarcity of research is that, in DMNEs, corporate strategies are more stable, with long-term perspective, what would require less frequent shifts in IOM. However, that is not the case for EMNEs: besides the turbulence in their home countries (Sull and Wong, 2005; Escobari and Sull, 2010), EMNEs are expected to systematically upgrade in GPNs, otherwise they will have their position menaced (Bartlett and Ghoshal, 2000). Moreover, it seems plausible to admit that, as infant multinationals, an EMNE will only be able to effectively change its strategy and moveup the GPN if it succeeds in reconfiguring its IMN. Therefore, the proposition to be demonstrated is:

There is a dynamic relationship between corporate strategy and international network configuration: multinationals will only be able to change strategic positioning if the international manufacturing configuration provides support for that shift.

4 –Methodology and fieldwork

In order to better understand how changing an EMNE's position in a GPN affects its IMN, it is necessary to get empirical evidence over a considerable time span. Therefore case study was the chosen method for this research. Two Brazilian multinationals, Embraer and WEG, were analyzed over a period of 20 years, which is when they expanded their presence in global markets as for both sales and production. They were chosen due to the following reasons:

- They are successful industrial EMNEs, with subsidiaries located in developed regions (Europe and North America) as well as in other developing countries, such as China, which means they operate in diverse economic and institutional environments;

- They were founded as a result of public economic stimulus: Embraer emerged from a governmental project for technological development while WEG started business in the wake of the Imports Substitution Industrialization;

- Embraer was born a state-owned enterprise (SOE) and was privatized; while WEG has always been private;

- They are largely connected to GPNs from their respective industries; according to the CbPF (Fleury and Fleury, 2007), Embraer can now be categorized as an Integrator (of Complex Product Systems) while WEG is essentially a Manufacturer;

- The evolution of their strategies and operations is largely documented.

In order to capture potentially different types of changes, the approach focus on the evolution of their IMNs as a whole, avoiding particularization for one product or business unit. Historical data was gathered and analyzed for further discussion with company executives at both the headquarters and subsidiaries where they are embedded. Such an approach led to the identification of potential contingency factors concerning network design and relationships between the network and strategic context. Due to the nature of the topic, very little documentation was available in the company, thus making historical data and interviews material as the main source of information. Triangulation was possible through the access to some related company presentation material.

Since this research explores the interaction between strategic level and the network level, extra care was taken to ensure that both levels were represented throughout the research process in order to ensure fit between data collection and the unit of analysis. Semi-structured questions were used during the sessions, with opportunities for clarification as well as collecting supplementary information between sessions. Most of the meetings had two researchers, one leading the discussion and the other taking notes and asking clarifying questions. Notes were compared after the meetings, and then shared with the executives for validation. Then, comparisons were made between the two EMNEs.

5 - The cases

5.1. EMBRAER: from local manufacturer to global first-mover in a hi-tech industry

Embraer is the world's third largest commercial aircraft manufacturer, with more than 5,000 airplanes produced up to 2013 and 19,000 employees in eight countries besides Brazil: USA (full-fledged subsidiary), France (sales and client support), Portugal (two plants for maintenance facilities and components production), China (manufacturing plant and client support), UK (sales and client support), Singapore (logistics hub), Ireland (sales office), United Arab Emirates (sales office). Its business units include commercial aircraft, executive jets, and defense and security.

1969-1994 – The local producer of a global product

Embraer was born a State-Owned Enterprise, to produce airplanes that would contribute for the development of inner country regions, under the doctrine of national sovereignty. Since the development of its first airplane, the company negotiated with large DMNEs for the acquisition of engines and avionics. Simultaneously, it was involved in partnerships with mid-sized Italian and American manufacturers for the local production of airplanes under license, as well as supplied a large American manufacturer with structural components.

Embraer was then part of a large national project and, as such, it had the support of a research centre and a school that provided highly skilled engineers, and support from the government as its client for both civilian and military products. In addition, Brazilian public banks created a financing scheme, to make feasible the global commercialization of Embraer's products.

Under those circumstances, Embraer's strategy was initially focused on domestic demands but, as airplanes are global products, exports started in the late 1970s. To make that strategy feasible, Embraer created a network of subsidiaries specialized in sales and after-sales.

Therefore, in the first stage of its history, Embraer was an isolated, vertically integrated aircraft manufacturer, assembling key modules imported from DMNEs, as well as selling small regional airplanes all over the world. According to Shi and Gregory (1998), Embraer's IMN configuration would then be categorized as Home Exporting Manufacturing (GMC1), because it had no transnational manufacturing operations, centralized manufacturing in home country and operated a global logistic system (for the acquisition of supplies).

1994-2001 – From local producer to leader of a global production network

At the time of its privatization, Embraer was in a delicate financial position. After privatization, the government gradually withdrew direct support, maintaining indirect influence through a "golden share" stake. Nevertheless, it remains Embraer's major client in the defense area, as it happens with other major global companies in the industry. For the turnaround, the acquiring private group gave Embraer a new strategic intent, with changes in its corporate mission, from technology-oriented to market-oriented, as well as new culture and organization.

The new product, the regional jet ERJ-145, was designed and manufactured under a radically new approach where Embraer created and led a network of four risk-sharing partners from Spain, Chile, Belgium and USA. These partners were, previously, common suppliers for Embraer.

In other words, the company reshaped its international network to be able to maintain its position in international markets. The new mission for its IMN was resource searching (from the partners) with tailored processes for the flow of information and knowledge among the risk-sharing partners, and standardized processes for the flow of parts and components that feed assembly lines.

For the most part of the second stage of its history, Embraer's IMN configuration remained a Home Exporting Manufacturing (GMC1), because it had no transnational manufacturing operations. For the most part, manufacturing and assembling was kept centralized in the home country but part of that became outsourced to risk-partners.

The ERJ-145 was extremely successful, despite the fierce rivalry with Bombardier of Canada, thus consolidating Embraer as a Global Integrator and leader of a global production network. That arrangement provided extraordinary competitive edge after the 9/11/2001. The flexibility of Embraer's global network allowed it to be the company that least suffered from the crisis that followed that tragedy: while its direct competitors succumbed one after the other, Embraer was able to manage its international operations to emerge as a new challenger in the aerospace industry.

2001- – A global player in the aerospace industry

In the 2000s' Embraer gradually consolidated as a Global First Mover. Its previous experience with decentralized global manufacturing allowed the company to assemble a much more complex international network for the production of its new jet, involving 11 renowned DMNEs like GE and Mitsubishi. At the same time, this GPN made possible for Embraer to diversify its global strategy by entering a new business: executive jets.

Embraer's IMN was gradually expanded. When it began to act as the leader of a network of risk-sharing partners, its position changed significantly: by "deverticalizing" production and strengthening its interface with suppliers, partners and markets, either airlines and their leasing companies or individual customers for executive jets. There is clearly a global-integrated manufacturing configuration (GMC3), according to Shi and Gregory (1998). But it has a regional orientation in what concerns sales and maintenance. This configuration is meant to lead to capabilities of resources accessibility and learning ability, to satisfy the main mission of market presence.

In sum, as a global first-mover in its internationalization strategy (Ramamurti and Singh, 2009), the reasons for going abroad are to acquire global customers and scale as well as to acquire key missing technologies and capabilities. It occupies a unique leading position in its GPN, as a complex systems integrator, although secondarily it is also a manufacturer and service operator (providing maintenance for the airlines). Companies such as Embraer, in high technology, fast-moving global industries are likely to develop innovative management models for their network-based organizations. Doz, Santos and Williamson (2001) classify Embraer as a metanational: an advanced multinational that "was born in the wrong place".

5.2. WEG: from low cost supplier to global consolidator of industrial equipment

WEG is one of the world's leading manufacturers of electric motors. Its global presence embraces subsidiaries in nine countries besides Brazil: Argentina, Mexico (3 plants), USA, India, South Africa (2), Portugal, Austria, Germany and China (4). Commercial offices are located in 28 other countries. WEG sells to over 135 countries and has 1,250 authorized repair shops covering all continents. Employment is over 28,000, 20% working abroad, in five business units: Electric Motors, Energy, Transmission and Distribution, Automation, and Coatings.

1969-1990 – WEG's foundation in the wake of the Imports Substitution Industrialization

WEG was founded in 1961 by three entrepreneurs, with the mission to produce domestically universal electric motors cheaper than those imported. WEG's first 20 years were a moment when imports substitution economic model was at its peak, and thus the company received support from the government to start business, as well as financial support especially for R&D purposes.

Located in Southern Brazil, the prevalent European culture led WEG to develop a strong organizational culture and embrace a participative management system, where decisions are made by committees. The structure is highly vertically integrated, from foundry and coating and assembling to sales and distribution.

Since the beginning, WEG has had a global mindset. Modest exports to neighboring countries started in the 1970s, in order to sell excess production, but during the 1980s exports became priority. The Exportation Department was created with the mission to open new markets, and to export even when returns were negative. The main objective was to learn how to serve sophisticated foreign markets and thus reshape the company's strategies. The R&D department was also created at that time.

Therefore, in the first stage of its history, WEG was an isolated, vertically integrated electric motor manufacturer for domestic markets, but with increasing exports, first to modest markets and then to more demanding markets. The limits of exporting through foreign distributors soon became evident, and WEG started to establish commercial branches, the first one in the USA. the Exportation Department was renamed International Department. The role of the commercial branches was to approach large clients while distributors would keep their role as suppliers to retailers. According to Shi and Gregory (1998), WEG's IMN configuration would then be categorized as Home Exporting Manufacturing (GMC1), because it had no international manufacturing operations, centralized manufacturing in home country and operated a global logistic system (for the acquisition of supplies and distribution of products).

1990-2003 – From home-exporter to low-cost partner

In the early 1990s, with the end of the Cold War and the new wave of globalization, WEG was ready to expand exports to a wide range of segments of electric motors, from universal to make-to-order products. One industry to which WEG has long been connected to is the hydraulic pumps GPN, where WEG maintains preferential relationships with pump producers. It was then categorized as a low-cost partner (Ramamurti and Singh, 2009).

The mission of its IMN was largely related to be present in preferential markets, but it became clear that it had to change its mission to dynamic responses, seeking closer relationship with its clients. The corporate supply chains are dispersed in many countries to access to the most optimized resources, markets and strategic capabilities according to the corporate strategic intentions. WEG used to distribute supply chains vertically and centralise each stage of process to reduce the duplication of manufacturing facilities. This configuration is meant to lead to capabilities of resources accessibility and learning ability, to satisfy the main mission of market presence. Thus, WEG moved to a Global-Integrated Manufacturing Configuration (GMC3).

2003- – From low-cost partner to global consolidator

In the 2000s, WEG decided to invest in foreign plants through acquisitions seeking, from the world's largest markets, those where legal and political stability prevailed. WEG has kept its main position as a world-class manufacturer, and its generic internationalization strategy shifted to global consolidator.

The mission of the network combines efficiency-orientation and flexibility-orientation. There is excess capacity and redundancy in different foreign plants, what was observed in the Chinese plant which exports almost half of its production to other subsidiaries. Recently, WEG changed its organizational structure: each foreign subsidiary was relocated to one of the five business units and the International Department became responsible for the commercial operations only. The aim of this change was to increase coordination and synergy between the foreign and the Brazilian plants.

Dispersion of WEG's IMN can be categorized as Worldwide due to the high number of subsidiaries present in a large number of regions and countries, to serve five business units. Governance follows a global pattern since units are horizontally coordinated and there is no hierarchy among them. Processes are both standardized and ad-hoc due to the specifics of the products and the business units. Therefore, the configuration is Global-Coordinated (GMC4) and network capabilities combine manufacturing mobility and thriftiness ability, to satisfy the mission of global competitiveness.

In sum, WEG is characterized by a high level of strategic entrepreneurship. Also, it is a global consolidator in its internationalization strategy, the reasons for going abroad are to acquire global customers and scale as well as to acquire key missing technologies and capabilities. It occupies a traditional position in its GPN, as a manufacturer, although secondarily it is also a technology supplier and service operator (providing maintenance for niche markets such as the flameproof motors).

6 - Discussion and conclusion

The two illustrative cases revealed a clear relationship between shifts in strategic positioning and the configuration of the international network. At this level of analysis, it is not possible to identify precedence in that relationship: strategy precedes network or network precedes strategy. It seems likely that there is a co-evolution between the two. Tables 1 and 2 show the evolution of both firms according to the adopted prioritization.

Table 1 – Embraer's timeframe

Time	International Strategy	CbPF	Main mission	Configuration	Capabilities
1969-1994	Exports	Manufacturer	Capability building	GMC1	Learning ability
1994-2001	Global 1st mover	Manufacturer	Resource searching	GMC1	Resource accessibility
2001-	Global 1st mover	Integrator	Market presence	GMC3	Resource accessibility

Table 1 shows that Embraer kept a GMC1 - Home Exporting configuration after the development of the ERJ-145 airplane. However, the international network put in place allowed the company to change towards GMC3 – Global Integrated configuration. In other words, the main assembly process was kept in-house (in Brazil), while the assembly of subsystems were transferred to the risk-sharing partners, for subsequent shipment to Embraer's main assembly plant. This restructuring is consistent with the new corporate strategy devised by the headquarters: becoming a Complex Product Systems integrator and a Global First-Mover.

In its current stage, new strategic options consolidated Embraer's GMC3 configuration: the opening of new international markets, as well as new strategic business units (executive jets).

One key evidence is the decentralization of the final assembly: commercial jets in the Chinese subsidiary (now switched to executive jets), and executive jets in the American subsidiary.

Table 2 – WEG's timeframe

Time	International Strategy	CbPF	Mission	Configuration	Capabilities
1961-1990	Exports	Manufacturer	Market presence	GMC1	Thriftiness
1990-2003	Low-cost partner	Manufacturer	Dynamic responses	GMC3	Resource accessibility
2003-	Global consolidator	Manufacturer	Global competitiveness	GMC4	Manufacturing mobility

Table 2 shows that WEG has kept is position as a manufacturer but gradually changed its strategy: from exporter to low-cost partner and global consolidator. It has productive capacity spread around the world serving distinct markets. But what is most important is its objective to become a global leader in the production of electric motors.

In its current stage, new strategic options led WEG to adopt a GMC4 - Global Coordinated configuration: opening new subsidiaries, via acquisitions or greenfield projects, as well as new strategic business units (coatings and automation).

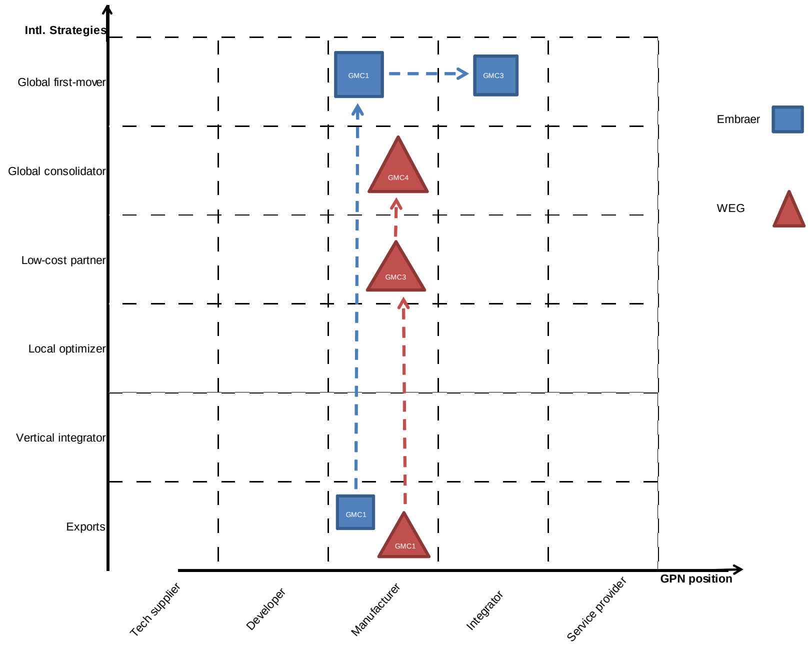

Figure 3 – Evolution of strategies and their respective network configurations.

From the illustrative cases, evidences that support the proposition were observed: changes in an EMNE's corporate strategy, which embraces the combination of generic internationalization strategy with the position in the GPN, are associated to relevant shifts in the configuration of IMNs. Figure 3 depicts the trajectory of Embraer and WEG in terms of their position in GPNs and generic internationalization strategy. For each strategy chosen there is an IMN configuration. WEG shifted its generic strategy and maintained its GPN position. As to Embraer, it shifted both generic strategy and GPN position.

From the standpoint of theoretical development, this study widens the lens in the analysis of international manufacturing networks by further integrating International Business concepts to the Operations Management framework. In addition, by considering that the firms' corporate and operational strategies are influenced by country of origin effects and position in the GPNs a new field of research is opened. Multinationals from an emerging country were studied but that seem not to be a constraint for the application of the analytical framework for multinationals of any other country.

This study has implications for researchers in that we show that strategic and network decisions are strongly interrelated and need to be considered in an integrated fashion. In addition to site location and site competence, the aspect of how markets are served from different plants need to be taken into consideration in the network design.

For managers, this research provides case studies and shows that changes, deliberate or not, in position in the GPN cannot be taken or seen in isolation. Instead, the relationship with the whole network must be considered.

Future research can propose new and updated configuration patterns for IMNs.

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Home network positions and the impact on internationalization

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Abstract

In this study, we explore how firms' local network positions may impact the degree of their internationalization. The relationship between local network centrality and the degree of outward foreign direct investment is examined. An interactive effect between networks with local firms and foreign firms is considered in our examination. Based on a survey of 194 Chinese firms, our findings are in twofold. First, firms with a higher local network centrality tend to be more active in internationalisation. This effect is different for firms with intermediary positions in their local networks. Second, the relational embeddedness in foreign firms' networks is positively associated with the degree of internationalisation; this positive association is significant for firms with a higher local network centrality.

Keywords: internationalisation; network position; foreign firms' network; relational embeddedness; centrality.

Home network positions and the impact on internationalization

1. Introduction

The increasingly active expansion by Chinese outward investors has been drawing an immense academic attention from both home and abroad. In 2012, with a total of US$87.8 billion outward foreign direct investment (OFDI) flows China became the world's third largest source country of OFDI (*Statistical Bulletin of China's Outward Foreign Direct Investment*, 2012). Traditional FDI theories, which were mainly developed based on multinational enterprises (MNEs) from the development countries, have to be verified in explaining the investment behaviours of MNEs from the emerging markets (EMs) (Buckley et al, 2007). Some scholars (e.g., Buckley *et al.*, 2007; Gu, 2011; Mathews, 2006) questioned the OLI paradigm (Dunning, 1995) regarding its power in explaining the investment patterns of EM-MNEs. They suggested that EM-MNEs, as the "latecomer" do not have the presumed first-specific advantages (FSAs) such as technological, managerial or brand advantages in their investments in the developed economies. Furthermore, studies on new investment ventures (INVs) or the "born global" firms suggest that in fact, some MNEs do not have to rely on early accumulation of overseas investment experience; Rather, OFDI provides a "springboard" for them to exploit home-based FSAs. The home-based FSAs can be the experience accumulated through the channel of inward FDI, networks and other strategic assets (Anderson *et al*., 2002; Luo & Tung, 2007; Oviatt & McDougall, 2005). The stage model (Johanson & Vahln, 1977) is also argued to have encountered difficulties in explaining the rapid internationalization processes of EM-MNEs.

A network perspective is gradually adopted to explain internationalization behaviours of EM-MNEs. For example, Johanson and Mattsson (1988) view internationalization processes as dynamic processes of network development. In such processes, firms try to establish international networks and develop new relational networks in order to secure appropriate network positions. Such research concerns the formation of host country-based network most. Guillen's (2002) study on Korean *chaebol* found that firms within the same business networks interact in order to obtain internationalization information, identify business opportunities, and reduce uncertainties. Mathews (2006) constructed the LLL theory which highlights *linkages*, *leveraging* and *learning* as the key sources of competitive advantages and global manufacturing networks as the main featured competitiveness of the OFDI latecomers. Along this line of argument, Zain and Ng (2006) empirically evidenced that network relations have important influence on both entry mode decisions and entry processes. Similarly, Yiu *et al*. (2007) suggest that relational assets embedded in firms' home country-based business networks play a crucial role in enabling internationalization. These more recent studies have focused on the home country-based networks.

In the case of China, the development inward FDI under the "bringing-in" policy and the development outward FDI under the "go global" policy co-exist. These two-way opening policies provide special institutional settings in shaping unique home country-based networks, which in turn, influence the OFDI behaviours of Chinese MNEs. Patel *et al*. (2014) found that networks with other local firms and foreign firms in the home country may provide different, yet complementary capabilities necessary for local firms' rapid internationalization. They argued further that attaining internationalization knowledge through foreign partners may increase coordination costs. However, approaching local partners can be cost effective, but obtaining only limited internationalization knowledge. Although both networks are regarded important, their impacts and the impact of their interactive effects on Chinese OFDI have not been sufficiently examined. Therefore, this study attempts to build the gap.

In this study, internationalization refers to the expansion of production or/and management from the domestic to foreign markets including exports, the establishment of overseas sales offices and R&D institutions, cross-border mergers and acquisitions, and other foreign direct investment activities. Home local networks (HLNs) refer to the networks established by focal firms originated in China. Specifically, HLNs connect focal firms with supply partners, customers, peer firms, government agencies, research institutions and universities, intermediary bodies and industry associations, etc. HLNs are regarded as the ego-centric networks (Greve, 1995) developed from the view of the focal firms. Foreign networks (FNs) in this study refer to the relationships between the focal firm mentioned above and the inward foreign investors in China, which can be based on joint ventures, strategic alliances, or OEM/ODM partnerships. The concept of FNs emphasizes the direct and long-term interactive relationships between the transaction parties based on their mutual understanding and trust as well as commitment (Uzzi, 1997; Gulati, 1998, 1999; Barden, 2007).

2. Conceptual framework and hypotheses

2.1 Network positions and their impact on the degree of internationalization

Network positions indicate the identity and influence of the focal firms in their networks, as well as the relational patterns of a relative stability (White, 2002). Due to different benefits that network positions may generate for firms, there are two different but interrelated network positions: central position and intermediary positions (Podolny, 2001).

2.1.1 Network central positions and the degree of internationalization

First, firms in the central positions of their networks usually have established direct relationships with many other firms. By doing so, the cost of searching information can be reduced and the efficiency of transferring information can be enhanced. Being in the central positions firms gain benefits not only from their larger number of network connections, but also from the potentially good quality of networks. This is because central positions may help them to gain trust and dependence by other firms. An increase of dependency of other firms tends to be positively associated with a higher frequency of interaction and resource commitment, thus improving the quality of cooperation (Rowley, Behrens & Krackhardt, 2000). Koka and Prescott (2008) believe that the above information-based benefits can help firms generate value in the new markets (such as identifying business opportunities or controlling key strategic resources, etc.). Therefore, comparing with other firms, those in the central positions of their networks may find it easier to obtain overseas networking information and establish direct overseas network relations (Johanson & Mattsson, 1988; Oviatt & McDougall, 2005).

Second, firms in the central positions of their networks can be more recognizable and more attractive than other firms, thus enjoy a higher social status and reputation (Powell， Kogut & Smith-Doerr, 1996) as well as higher capabilities of legitimacy (Gould, 2002). It is well argued that firms may suffer from the liabilities of foreignness when they enter into foreign markets; they may have little compliance experience for international operation or have difficulties in building trust with potential partners, suppliers and customers (Hymer, 1976; Kindleberger, 1969; Zaheer & Venkatraman, 1995). In such a case, firms' central positions in their networks can positively influence the perception of potential partners (Perrow, 1961). Due to the signalling effect of networks central positions signal the market a guarantee of good quality (Podolny, 2010: 18, 35, 38). In other words, central positions become valuable resources for firms to enter into new markets. Central positions become an advantage when firms enter into a market with imperfect and uncertain information. Central positions send positive indication and reference to the market consequently facilitating firms to establish new relations and exchanges (Podolny, 2001; Guler & Guillen, 2010). Such an advantage can be more important for firms in the process of internationalization. The above argument supports our first hypothesis.

Hypothesis 1: Firms' central positions in their networks are positively related to their degree of internationalization.

2.1.2 Network intermediary positions and the degree of internationalization

Firms in the intermediary positions of their networks are the bridges that connect decentralized and non-repeating links among different groups of firms (Burt, 2000). These kind of firms have more accesses to network resources, and can obtain earlier those novel and diversified information and knowledge (Burt, 2000; Zaheer & Bell, 2005), thereby controlling the flow of network resources. By occupying the "structural holes" of the networks, these firms can control their gains (Zaheer & Mcevily, 1999). But the intermediary role of a bridge must be played among groups of different background information. Therefore, their advantages come from the diversity of network partners (Koka & Prescott, 2002). In the meanwhile, because their advantages have stickiness (Gabbay & Zuckerman, 1998; Xiao & Tsui, 2007), the advantage is "a temporary, local advantage" (Burt, 2005). In addition, potential partners believe firms in the intermediary positions are opportunistic and do not regard them as good potential partners in the new network (Burt, 2007). Because of the advantages of firms in the intermediary positions are context-dependent, these firms do not have significant advantages when they enter into the overseas markets (Guler & Guillen, 2010). Based on the above analysis, we have the following hypothesis.

> Hypothesis 2. Firms' intermediary positions in their networks are negatively related to their degree of internationalization.

2.2 Foreign network embeddedness of and the impact

2.2.1 Direct impacts of embeddedness in foreign networks

Research based on network theory supports the view that knowledge gained through inter-firm and market connections helps overcome the liability of foreignness and smallness (Hymer, 1976; Patel et.al. 2014). In particular, the ability to develop and obtain supports from other firms such as suppliers and distributors in foreign markets provides a multinational firm a significant source of learning about different markets (Aitken *et al*., 1997; Eriksson *et al*., 2000; Johanson & Mattsson, 1988). As the institutional and business knowledge must be current and country-specific, existing collaborative partnerships from a foreign country of interest represent an efficient means for gaining such knowledge (Patel et.al. 2014). Such collaborations can potential shorten the "psychological distance" (Psychic Distance) between home local firms and the overseas markets (Beckermann, 1956). Communications with foreign-invested firms of a shorter geographic distance help local firms to identify potential business opportunities in overseas markets, thus increasing their propensity of overseas expansion (Gu & Lu, 2011). Based on the above analysis, we propose the following hypothesis:

Hypothesis 3: Embeddedness of local firms in foreign-invested firms' networks has a positive impact on the formers' degree of internationalization.

2.2.2 Interactive impacts of embeddedness in foreign networks

The direct communication between the local and foreign firms helps both firms to transfer tacit knowledge to each other (Larson, 1992). Luo and Rui (2009) argued that the experiences of inward foreign direct investors may have contributed a catalyst to EM-MNEs' accelerated international expansion. For example, Koka and Prescott (2008) suggested that foreign-invested firms in China tend to have certain advantages such as talents, advanced technologies and managerial knowledge. These firms usually prefer to collaborate with local firms which stay in the prominence of central positions in their local networks. Their collaborations typically start from relatively weak ties and take a long time to develop due to additional resources required to maintain and leverage their relationship further (Dellestrand & Kappen, 2012). Because establishing and maintaining a long-term relationship can be costly, not all local firms but those in the central positions of their local networks are more likely to get engaged. The higher degree of resource commitment, the more frequent the collaborations, and the more possible to enhance the quality of collaboration between both the local and foreign partners. This interactive effect can directly get local firms enriched with information they need (Levin & Cross，2004；Luo&Tung, 2007). The effect can also send positive signals about the local firms to the market (Gulati & Higgins, 2003; Zaheer & Bell, 2005), which in turn, improves the centrality of local firms further.

Now, let's move to firms in the intermediary positions of their networks and their collaboration relationships with foreign firms. From the investment point of view, their collaborations are not repeatable due to the relative weak relationships. Of course, for such kind of collaboration, the coordination cost is less. The structural holes are minimized by reducing redundant communications (Zaheer & Mcevily, 1999). This type of local firms tends to be closer to diversified information about foreign markets. They seem able to secure more information about overseas operation and to have advantages of keeping and controlling the certain information. Walker and others (1997) studied the conditions for structural holes to function. They found that structural holes may function in contractual relationships. However, for collaboration relationships, structural holes have to function by playing the "third party" role. Given trust and loyalty between the collating parties are crucial for their success, the third party role of structural holes for strengthening the partnerships is not obvious. For the same reason, local firms featured by intermediary positions in their local networks tend not be the important partners for foreign firms in China. Because of limited capacities and resources, these local firms tend to adopt alliances as the main approach for overseas operation. The more that firms are featured by this intermediary network positions, the more likely these firms set up alliances with foreign firms based on relatively weak relationships. What these local firms tend to pursue is to set up an effective and information-intensive bridge between the local networks and foreign networks at the lowest cost. By doing so, they try to strengthen their intermediary positions further in the local networks, although such efforts may not substantially resolve the stickiness of their information in the local networks. Thus, we have the following two hypotheses.

H4. A strong embeddedness in foreign networks strengthens the positive impact of local firms' central positions on the degree of their internationalization.

H5. A weak embeddedness in foreign networks strengthens the negative impact of local firms' intermediary positions on the degree of their internationalization.

3. Methods

3.1 Sample and data collection

The study adopts survey to collect data regarding collaboration relationships among different firms, the internationalization status, as well as external business environment. Since the majority of the questions require respondents involved in the overall operations, especially the situation of international, therefore, respondents have been rigorously screened. Corporate officers with more than three years of senior management experiences were selected mostly. Firms engaged in internationalization were selected. We piloted and pre-test for the instrument validity by randomly selected 50 samples. The data was collected through three main channels: 1) the third party research agent which is the main channel of data collection; 2) direct collection from the field work by the authors; 3) MBA and EMBA classes. Eventually, 194 valid samples were collected as summarized by Table 1. We also randomly selected 20 samples with firms names indicated. We double checked data provided by the survey against actual information from company report (e.g., the establishment year of the overseas operation and firm size) verify the accuracy of the data. The results showed a high consistency between their website reports and their survey answers. ANOVA analysis indicated no significant differences on the number of employees and firm age across the three groups of respondents. We are confident that the sample bias is not a concern.

Table 1 is about here

3.2 Common method bias

We use 5 likert scale and 7 likert scale for collecting data for different variables. The actual data were re-calculated based on our requirements. Further，we conducted a Harman’s post-hoc single factor test (Livingstone, 1997), wherein all variables are allowed to load onto a single factor. All the variables were entered into an exploratory factor analysis, using unrotated principal components factor analysis, revealed the presence of 6 distinct factors with eigenvalue greater than 1.0 which together accounted for 68.876% of the total variance among the variables. The first (largest) factor did not account for a majority of the variance (25.186%). So the model demonstrated very poor fit (the model failed to converge), suggesting that there are no significant common variance threats (Wang & Luo, 2014).

3.3 Measurement

Table 2 shows the detailed Cronbach’s alphas, factor loadings, and related prior studies we referenced when developing question items for the major variables used in our study. We conducted both exploratory and confirmatory factor analyses. Loading patterns in both analyses clearly differentiate across variables and factor solutions consistent with our hypotheses.

Table 2 is about here

Existing literature has not suggested conclusive measures on the degree of internationalization. For example, Sullivan (1994) has experimented with five economic indicators to measure the degree of internationalization. In this study, we use multi-nationality index from World Investment Report 2000: Development of Cross-border Mergers and Acquisitions by UNCTAD. Accordingly we designed 10 different grades as the proxy of different degree of internationalization. Each grade is calculated based on the average of three measures: the ratio of foreign assets to total assets (FATA), the ratio of foreign sales to total sales (FSTS), the proportion of overseas employees to total employees (FETE).

To measure firms' network positions, we use "network-centric self-analysis method" (ego-centered networks) and treat "discussion of the network" as the carrier (Greve, 1995). Measurements of the two types of network positions are discussed below.

Central positions in the networks: Koka and Prescott (2008) indicated that centrality, size of the firm's network, the number of ties can be three indicators to measure the extent a firm is in a central position of its networks. Because our data is cross-sectional, we focus on two measures: centrality and network size. First, according to Koka & Prescott (2008) we created three items to measure centrality, namely the frequency, tightness and importance of network ties that a firm links with its partners. Second, we use the total number of partners of a focal firm to measure its network size. The partners include customers, suppliers, peers, other organizations (government agencies, research institutions, intermediaries, industry associations, etc.). These partners are grouped by four categories; each category has seven levels to suggest different sizes.

Intermediary positions in the networks: Based on Koka and Prescott (2008) we adopted the concept of network heterogeneity and structural holes (non-redundancy) to measure firms' intermediary positions in their networks. Network heterogeneity is captured by the method of "discussion networks" from Greve (1995). Accordingly, respondents need to discuss the top five most important but different partners of their entire networks. We selected two major dimensions: partner type and partner location to capture network heterogeneity. In addition, we have two items to measure business status between the sample firms and their partners. Using the same method by Agresti and Agresti (1978) in creating Index of Qualitative Variation (IQV) we calculated the heterogeneity index for our study. We also followed the same method of Zaheer and McEvily (1999) to measure non-redundancy network ties. In specific, respondents were asked to cite the top five most important organizations or individuals among the partners and to indicate the degree that these organizations or individuals may connect or know each.

Embeddedness in foreign networks: This variable is set to capture the relationships between the focal firms and the foreign firms. It emphasizes whether the relationship is a dual inter-connected relationship, by which the two transaction parties are directly and interactively connected on the condition of mutual understanding, trust and a long-term commitment. We noted that foreign firms may interact with local firms through various forms. For example, they may connect with local firms from both the upstream and downstream of the value chain or through strategic alliances. Consequently, foreign firms' networks become an organically-developed and unique part of the home country networks. We extracted arguments from Uzzi (1997) on trust, information-sharing and jointly-resolving problems and form three items respectively to measure embeddedness of focal firms in the networks of foreign firms.

Several control variables are considered, they are: international experience, firm size, firm age, ownership and industry. *International experience* is measured by the total years of foreign operation by 2013. *Firm size* is measured by the total number of employees. *Firm age* is measured by the total years of establishment till 2013. All the above measures are in natural logarithm. For *ownership*, a dummy variable is used to set state-controlled enterprises to “0” and non-state-owned enterprise “1”. Finally, *Industry* dummy is set up to consider different technology intensity. Accordingly, industries such as software, electronics, telecommunication, biotechnology, as well as new material industries are set to “1” and traditional machinery manufacturing, chemical, and textile industries is set to “0”.

4. Analysis and results

Table 3 reports means, standard deviation, and Pearson’s correlation coefficients for all variables used in this study. The correlation among the independent variables and other diagnostic tests we conducted suggests no threat of multicollinearity (maximum variance inflation factor is 1.872, the model 7 in table 6).

Table 3 is about here

To examine the network positions and their impact on the degree of internationalization, we used multiple linear regression method. Table 4 shows the hypothesized results of main and interaction effects based on four models. The dependent variable is the degree of internationalization.

Table 4 is about here

The results of Model 2 suggests a significant positive association between network centrality and the degree of internationalization (β = 0.458, $p < 0.05$). It also suggests a significant positive association between network size and the degree of internationalization (β = 0.146, $p < 0.1$). According to both results, hypothesis 1 is supported. The results of Model 3 suggests a significant negative association between network heterogeneous and the degree of internationalization ((β = -0.537, $p < 0.05$) as well as a significant negative association between non-redundant networks and the degrees of internationalization (β = -1.098, $p < 0.1$). According to both results, hypothesis 2 is supported. When also considering all explanatory variables in Model 4 the results are consistent with the one from Model 2 and Model 3, thus our results are valid and stable.

To examine the impact of embeddedness in foreign networks, we add this variable and related interactive variables to main test. Table 5 shows the results four additional models. The dependent variable is the degree of internationalization.

Table 5 is about here

Model 5 shows a significant positive relationship between embeddedness in foreign networks and the degree of internationalization (β = 0.384，$P<0.05$). This result supports our hypothesis 3. Model 7 shows when the variable of embeddedness in foreign networks interacts with two different variables of central network positions, both have significantly positive effects on the degree of internationalization (β = 0.761, β =0.255, with $P<0.05$). These interactive effects support our hypothesis 4. In the meantime, the R^2 value is significantly improved. We plotted the interaction terms to double-check the significant effects. Figure 1 and 2 further confirm our proposed paths of creating the effects. Model 8 shows when the variable of embeddedness in foreign networks interacts with two different variables of intermediary network positions, there are positive but no significant effects on the degree of internationalization. In the meantime, the R^2 value is not significantly improved. Accordingly, out hypothesis 5 cannot be supported.

Figure 1 and Figure 2 are about here

5. Discussion and conclusion

Our results show that firms' central positions or intermediary positions in their home networks have different impact on the degree of their internationalization. Our findings support the argument that central positions in home local networks may introduce rich information, enhance firm's reputation, lower the cost legitimacy, and reduce the uncertainties and liabilities of foreignness, thus increasing the possibilities of internationalization. In comparison, firms' intermediary positions in home local networks create advantages based on the control information flow and dissemination. This kind of firms tries to build networks with variety types of partners in order to create value through bridging the structural holes. Such intermediary advantages, however is constrained by the stickiness to location. Therefore, unlike firms in the central positions of their networks, they do not have the advantage to transfer their advantages. In fact the intermediary advantages reduce the likelihood for making overseas expansion. Our results support the findings by Guler and Guillen (2010) that firms in the intermediary positions in their networks are less likely to internationalize.

Our findings suggest a positive impact of foreign investors on local firms' overseas investment. Consistent with the results of previous studies (Aitken, Hanson, & Harrison, 1997; Kneller & Pisu, 2007; Luo & Tung, 2007), Chinese local firms can learn how to internationalize from the inward foreign investors (especially on the tacit knowledge). Through learning, they can obtain the necessary internationalization experience to enhance FSAs (Clarke et. al. 2013). We also found that the embeddedness in foreign networks strengthen the positive impact of central network positions on the degree of internationalization. This effect confirms the findings by Jesen et al., (2003). They argued that embeddedness in foreign networks reduces market uncertainty by increasing familiarity, and also increase exchange value by facilitating the development of trust. In addition, the central positions in networks reduce market uncertainty by signaling quality and increases exchange value by contributing to social identity. Both, when interacting, can further enhance the FSAs and internationalization.

We note that Model 8 shows a positive but no signification ($p>0.1$) results on the interactive effects between the intermediary network positions and the embeddedness in foreign networks. To explain this result, we refer to Jesen *et al*. (2003). They pointed out that familiarity and trust based on relational embeddedness develop between firms are a more direct mechanism for reducing market uncertainty. In other words, the correlation between the perceived reduction of market uncertainness (based on our data) and the degree of internationalization may not be straight forward.

With regard to the findings based on the control variables, international experience has a significantly positive correlation relationship with dependent variable in Model 1-8. This result has been evidenced by many previous studies such as the experiential learning theory and stage model (Johanson & Vahlne, 1977, 1990; Welch & Luostarinen, 1988). With accumulated overseas experience firms can identify risks and opportunities, make more appropriate business decisions and better manage overseas institutions (Prasad, 2006; Clarke et al, 2013). Firm age has a significantly negative correlation relationship with dependent variable in Model 1-8. This result is not consistent with previous findings. Majority studies suggest that the longer the time of establishment, the larger the size enterprises, hence usually the more abundant resources (Hannan & Freeman, 1984; March & Simon, 1958). To explain our finding, we argue that firms with long history and large size can be relatively rigid and inertia in making changes (Hannan & Freeman, 1984; Ranger-Moore, 1997). In comparison, NIVs are known to suffer from the liabilities of newness and smallness (Zaheer, 1995). They can be motivated to overcome these challenges through an increased reliance on networks (Oviatt & McDougall, 1994).

We must admit the limitations of the study. First, we rely on self-reported data that future search needs to bring in actual data. Second, we are limited with a relatively small sample size that better channels of data collection deserve more attention. Third, we did not collect performance data hence only the degree of internationalization and its relationship with network position are examined.

We draw three key implications from our findings to conclude this primary research. First, Chinese firms should strengthen their network capacities to gain competitive advantages.

Attention should be given on issues such as how to build up home local network and adjust positions in the networks in the formation of international strategy. Second, inward foreign direct investors provide Chinese firms with valuable and cost effective learning platforms to shorten the cultural distance. Chinese firms need to find better approaches to make full use of network resources of foreign firms.

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Tables

Table 1 Responding results of the questionnaire

Channels of Data Collection	Total disseminated	Total returned	Responding Rate	Valid Response	Rate of valid response
Third party research	200	162	81.0%	127	78.4%
Fieldwork	68	49	72.1%	35	71.4%
(E)MBA classes	89	43	48.3%	32	74.4%
Total	357	254	71.1%	194	76.4%

Table 2 Major measures and factor loading results

Items	Loading	α
Degree of internationalization (UNCTAD,1998, 10 grades)		0.762
Ratio of overseas assets to total assets (FATA)	0.914	
Ratio of overseas sales to total sales (FSTS)	0.749	
Proportion of overseas employees to total employees (FETE）	0.852	
Discuss the central positions in home local networks (Giuliani & Bell, 2005； Johannisson et al., 2002, 5 Likert scale)		0.744
Exchange technological, production and market experiences and knowledge often with the partners	0.823	
Have very stable relationship with partners	0.577	
Your partners often expect you to provide new knowledge and experience (technological, production and market) when needed	0.797	
Home local network size (Burt, 2000; Jarillo, 1989; 7 different grades)		0.815
Number of exchanges with customers	0.864	
Number of exchanges with main suppliers	0.862	
Number of exchanges with peer firms in collaborations	0.766	
Number of exchanges with others (government agencies, research institutions, intermediaries, industry associations)	0.821	
Embeddedness in foreign networks (Zaheer, McEvily & Perrone, 1998; McEvily & Marcus, 2005; 5 Likert scale)		0.761
Foreign partners and your firm trust each other’s commitment	0.780	
Foreign partners and your firm try to provide useful information to each other	0.768	
Foreign partners and your firm can fulfil a mission and task together.	0.751	

Table 3 Summary statistics (mean, standard deviation, and correlations)

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10
1 Industry	0.48	0.50										
2 Ownership	0.69	0.46	-.022									
3 Firm age	1.21	0.28	-.171**	-.286***								
4 Firm size	2.91	0.73	-.048	-.335***	.464***							
5 International experience	0.87	0.29	-.118	-.095	.571***	.389***						
6 Centrality	4.25	0.49	-.034	.050	.024	.104	.148**					
7 Network size	3.61	1.22	-.016	-.090	.207***	.286***	.198***	.109				
8 Non-redundant connections	1.13	0.49	-.003	.041	-.067	-.129	-.107	-.081	-.185***			
9 Network heterogeneity	0.95	0.15	-.060	-.007	-.021	.013	-.064	.092	.136	.044		
10 Embeddedness in foreign networks	4.09	0.58	-.011	-.017	.068	.111	.161**	.553***	.174**	-.141	.084	
11 Degree of internationalization	2.75	1.28	.020	.096	-.064	.016	.160**	.222***	.152**	-.225***	-.153**	.213***

Note：*** significant level, P<0.01 (two-sided)； ** significant level P<0.05 (two-sided)

Table 4 Central positions, intermediary positions and their impacts on the degree of internationalization (regression analysis)

variables	Model 1		Model 2		Model 3		Model 4	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Constant	2.588	.000	2.611	.000	2.595	.000	2.622	.000
Industry	.049	.790	.055	.759	.019	.914	.020	.907
Ownership	.199	.346	.160	.441	.201	.328	.159	.428
Firm size	.056	.701	-.034	.815	.027	.852	-.055	.700
Firm age	-.985**	.023	-.939**	.028	-.958**	.023	-.913**	.028
Internationalization Experience	1.226**	.002	1.048**	.007	1.099**	.004	.914**	.015
Centrality			.458**	.013			.475**	.009
Network size			.146*	.057			.144*	.059
Network heterogeneity					-.537**	.003	-.452**	.012
Non-redundant network					-1.098*	.059	-1.422**	.014
R^2	.066		.116		.127		.181	
R^2 Variance	.066		.051		.061		.065	
F	2.654**		3.515**		3.873**		4.411**	

Note：dependent variable: degree of internationalization, N=194； * P<0.10; ** P<0.05; Maximum VIF is 1.757 in Model 4.

Table 5 Embeddedness in foreign networks and interactive effects on network positions

Variables	Model 5		Model 6		Model 7		Model 8	
	B	Sig.	B	Sig.	B	Sig.	B	Sig.
Constant	2.592	.000	2.619	.000	2.397	.000	2.610	.000
Industry	.048	.791	.017	.921	.083	.628	.033	.849
Ownership	.193	.355	.165	.414	.225	.254	.162	.423
Firm size	.036	.804	-.051	.717	-.047	.737	-.046	.748
Firm age	-.943**	.028	-.913**	.028	-.690*	.095	-.832**	.048
International Experience	1.107**	.005	.896**	.018	.823**	.028	.847**	.026
Embeddedness	.384**	.015	.164	.368	.193	.285	.196	.295
Centrality			.372*	.082	.557**	.013	.370*	.095
Network size			.136*	.078	.139*	.065	.137*	.076
Non-redundant network			-.441**	.014	-.465**	.010	-.434**	.016
Network heterogeneity			-1.442**	.013	-1.063*	.064	-1.291**	.030
Centrality * Embeddedness					.761**	.025		
Network size* Embeddedness					.255**	.040		
Non-redundant * Embeddedness							.043	.894
Heterogeneity * Embeddedness							.732	.244
R^2	.095		.181		.231		.188	
R^2 Variance	.095		.086		.050		.007	
F	3.287**		4.057**		4.535**		3.491**	

Note：dependent variable: degree of internationalization, N=194； * P<0.10; ** P<0.05; Maximum VIF is 1.872 in Model 7.

Figures

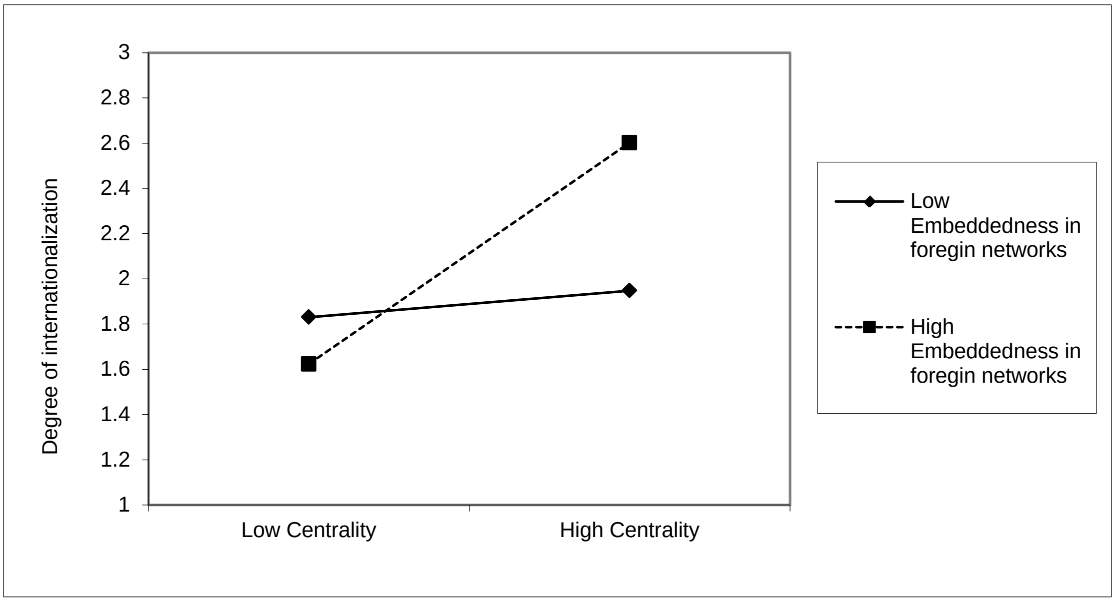

Figure 1 Embeddedness in foreign networks and the impact of central positions on the degree of internationalization

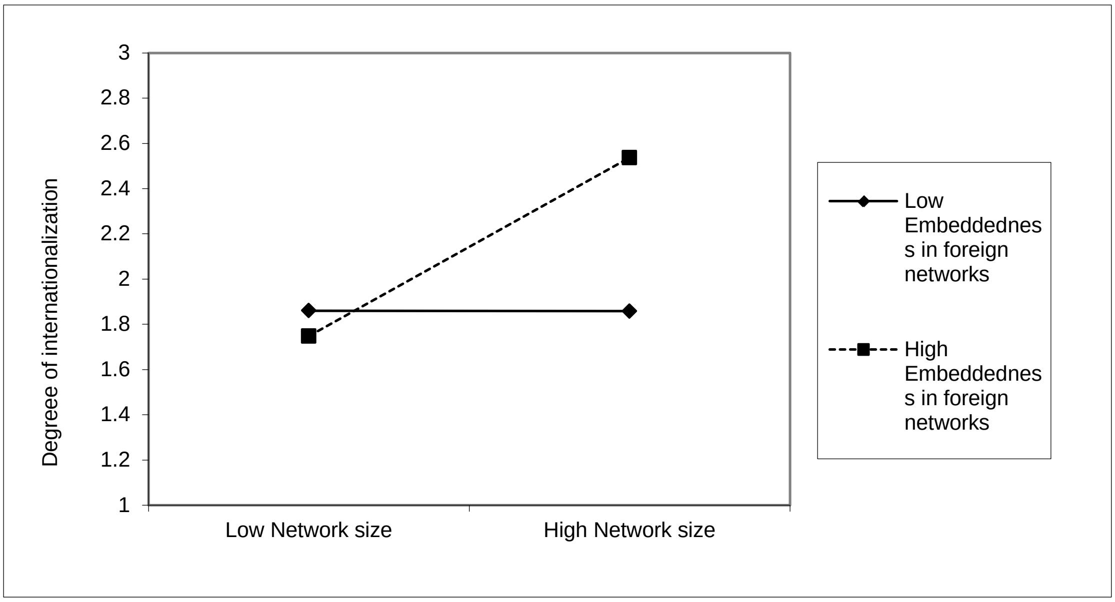

Table 2 Embeddedness in foreign networks and the impact of network size on the degree of internationalization

Customer-driven Planning and Control of Global Production Networks – Balancing Standardisation and Regionalisation

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Abstract

An increasing and volatile demand in emerging economies challenges manufacturing companies to decide, whether the new markets can be satisfied with the existing product portfolio, or to which extent it has to be adapted to meet the regional market requirements. A three-step approach to enable globally operating companies to efficiently deliver innovative products adapted to regional requirements regarding product design and functionality is presented. In the first step a bottom-up process is formulated on how to design customer-oriented products for frugal innovation integrating the customer directly in the design process. In the second step a methodology to design production systems in accordance with the customised products including the customer in the order-fulfilment process is composed, while in the third step a multi-objective optimization approach is developed to strategically design production networks and to plan and control the designed networks on an operative level taking dynamic business environments into account.

Keywords: Production networks, local production systems, customisation, frugal innovation

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1. Introduction

The current situation within the manufacturing industry is characterized by an ongoing globalisation. The lack of growth opportunities in the domestic market and a strongly increasing demand in emerging economies such as Brazil, Russia, India, and China (BRIC economies) due to a rapid growth in population as well as an increasing wealth force companies to globalize their production activities. It is estimated that the worldwide real gross domestic product (GDP) will increase from 73 trillion USD in 2010 to 377 trillion USD in 2050. Figure 1 illustrates, that the share accounted for by North America and Western Europe is expected to fall from 41% in 2010 to 18% in 2050, while Developing Asia's share is predicted to rise from 27% of world GDP to 49% in 2050 (Buiter and Rahbari, 2011).

In addition to this quantitative shift of demand, new customers in these emerging markets often require different products in terms of functionality and designs with different features, quality and price points forcing manufacturing companies to offer more varieties resulting in a larger amount of stock keeping units (SKU) and decreasing production efficiency. Figure 2 illustrates the share of regionally adapted product design compared to globally standardised product design distinguished by industries. At the same time, customers in more established domestic markets are demanding greater customisation and faster product cycles pushing companies to churn out new innovations and new products in even shorter times and greater frequency.

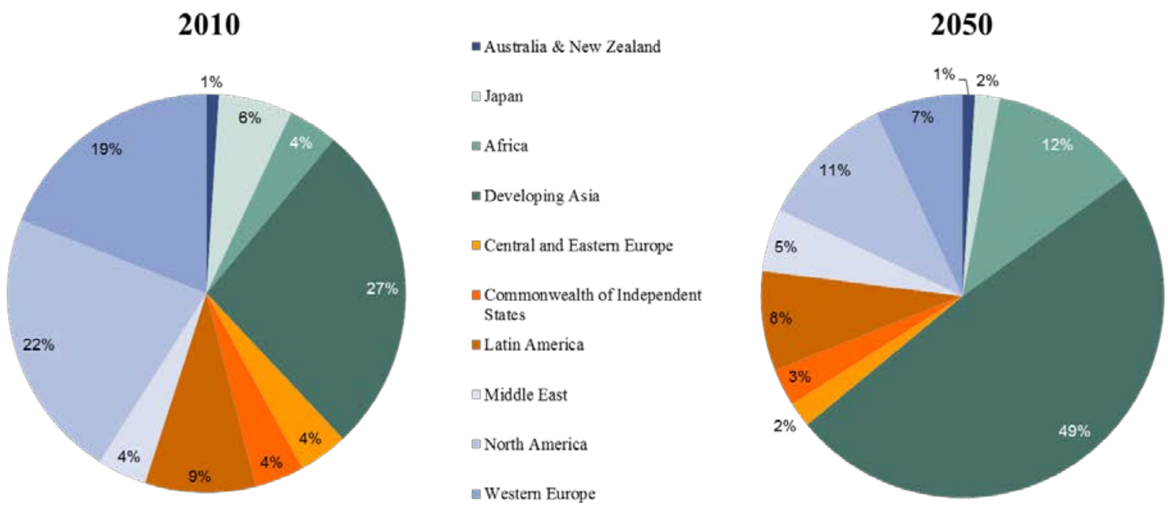

Figure 1: Regional distribution of world real GDP in 2010 and 2050 (Buiter and Rahbari, 2011)

Innovative information and communication technologies (ICT) are entering the terrain of traditional industrial processes. Germany forces this development by a national initiative called "Industrie 4.0". Similar programs exist in the EU Horizon 2020 program and in the US. So called cyber-physical systems (CPS) will create new opportunities for production by increasing transparency inside a factory but also along the supply chain - from the end customer over the company-internal production network to the raw material supplier. Moreover, customer feedback can be integrated using innovative coordination mechanisms based on real-time information. Thus, future industrial production may allow for increasing individualisation of products which are linked to each other and to the internet by integrated ICT functions.

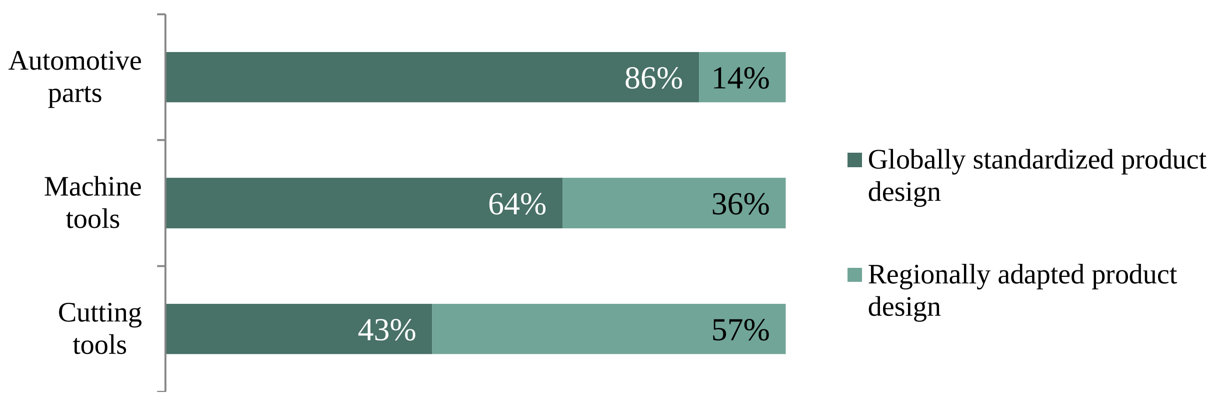

Figure 2: Share of alternative product designs in different industries (Abele 2008)

Hence, central challenge for the future manufacturing industry will be to get a comprehensive understanding of customers' requirements to figure out which product functions are really valued in which region. The resulting question will be, to which extent a company has to adapt its existing product portfolio in order to meet regional market requirements. Since the challenge of global production is structured by means of the three coherent focus levels product, production system, and network as well as their interdependent cause-effect relationships, in addition the question has to be answered, how the local production system and the superordinate network structure have to be strategically designed as well as operatively planned and controlled taking advantage of innovative CPS.

Therefore the paper is structured as follows: After presenting the objective of the approach in chapter 2, chapter 3 proposes basics of the above mentioned different focus levels product, production system, and production network as well as cyber-physical systems as a key enabler. In chapter 4 the proposed methodology is presented in a three-step approach, whose elements are presented in Figure 3 in relation to the different focus levels of research. Finally chapter 5 concludes the proposed approach.

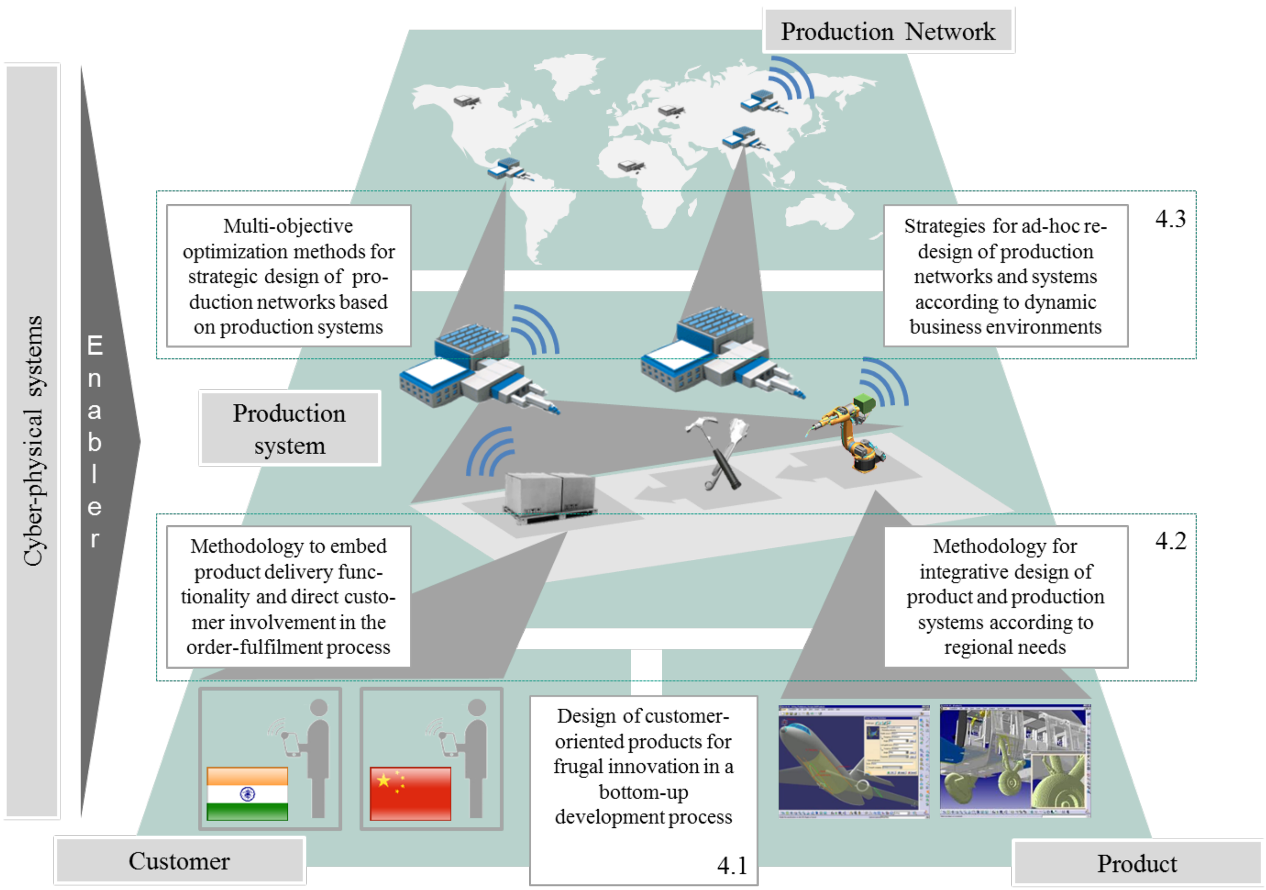

Figure 3: Relationship of overall approach and focus levels of research

2. Objective

The objective of the proposed approach is to enable globally operating companies to efficiently deliver innovative, customised products by using their globally distributed production network to meet the strongly differing regional requirements regarding product design and functionality of their globally distributed customers.

In order to reach the objective the customer has to be integrated in a bottom-up approach into the product development in a first step. Working (almost) in real-time this approach must allow for an efficient incorporation of strongly differing customer requirements. Since the development of a product is closely interlinked with its production planning, a manufacturing intelligence based methodology has to support the integrated design of the product and the related production system incorporating the customer in the order-fulfilment processes. Supported by a knowledge based engineering tool this ensures an effective manufacturing and delivery of customised products and related services. The production network has to be designed in a third step according to the single production systems. By multi-objective optimisation methods the product variants derived from customer requirements and related adapted manufacturing technologies are allocated to existing production sites. In addition to the allocation of manufacturing technologies, a comprehensive coordination mechanism between the production sites has to be implemented, which can be supported by Cyber-physical systems ensuring a smooth data exchange. Besides a strategic design of the production network, methods for tactical planning and control have to be developed taking restrictions of local production plants as well as specific customer requirements for product variants and functionalities into account. They allow a modification of the production network in order to react to external influencing factors due to dynamic business environments.

3. Background

In the following sections, basics of the above mentioned different focus levels product, production system, and production network are proposed. Furthermore, the state-of-the-art regarding CPS and their potentials for production are presented.

3.1 Product level

Gearing product design towards a defined objective is common in research on product design. It is internationally referred to as of Design for X (DfX) and generally covers all approaches and methods that are meant to achieve a specific objective. Guidelines for Design for Manufacture (DfM), for example, are meant to design manufacturing processes as economical as possible through adequate product or component design (Boothroyd et al., 2002). Other objectives include Design for Assembly, Safety, Ergonomics, Disassembly, Quality, and Service. Current research activities also look into Design for Supply Chain (Hurschler and Boutellier, 2008) or Design for Logistics (Dombrowski et al., 2008). However, Design for Manufacture is the most widely used as it is tailored towards the reduction of manufacturing costs and therefore is of general relevance (Ulrich and Eppinger, 2011). A tested and formalized design principle that directly integrates customers during the product design of a series product does not exist. Today customer feedback is mainly collected after sales e.g. by interviews or online surveys. Further research approaches in product design are aiming to achieve specific cost targets or cost reductions in order to allow for products to be offered on global markets at favourable prices. Even though many authors point out the need to adapt product design to regional customer requirements, no integrated methodology has been developed so far. The impact of cause-effect relationships between customer-specific product design and manufacturing processes available at specific production locations have also yet to be examined.

Frugal (described by Roland Berger (2013) as functional, robust, user-friendly, growing, affordable and local) innovation is the process of reducing complexity and cost of a good and its production. As a process, frugal innovation discovers new business models, reconfigures value chains, and redesigns products to serve users who face extreme affordability constraints (Roland Berger, 2013). Emerging markets with a growing aspirational middle class create perfect conditions for frugal innovation (Bound and Thornton, 2012). With the growing emphasis on high industrial efficiency and minimal environmental impact during the creation and use phases of products the current trend opens a wide opportunity for the development and implementation of frugal innovation strategies (Tiwari and Herstatt, 2011). The past history and the future industrial prospects of frugal innovation are vast and take a new perspective by injecting the idea of frugality to translate it into a new business model. Industrial applications include production of goods e.g. in the automotive industry, information and communication technology as well as service industries. Recently, several studies have investigated the potentials of frugal innovation and frugal engineering for Western companies gaining market shares in emerging markets as well as proposing new affordable products with increased sustainability performance for the domestic market (Mundim et al., 2012).

Bhatti and Ventresca (2012) present overall challenges and opportunities as well as contemporary marketing and social drivers for frugal innovation and resulting implications to the academic research and industrial practice. Rao (2013) characterized and formalized the frugal innovation process based on examples in comparison with ordinary innovation. Therefore, structural comparison and evaluation of frugal innovation is done by supporting evidence obtained from globally operating companies (Rao, 2013). How frugal innovation can be exploited for co-creating with customers, empowering engineers, and taking a clean slate approach to product development is also discussed in other works, which also emphasize, how this approach may offer leverage for companies not only in the regional but also in the global market (Jha and Krishnan, 2013).

Although all these industrially and scientifically driven studies have stressed the importance of frugal innovation in future global industrial competition, there is evidenced lack of formalized product/service development approaches and supporting tools to integrate customers' feedback in the innovation process and to lift frugal innovation to the production planning stage. Moreover, the implications of frugal innovation with design and organisation of production networks, cooperation mechanisms, and order assignment are neglected. Furthermore, technical requirements for production systems supporting customer-driven frugal innovation are not yet standardised. Finally, there is no specific strategy to use CPS as enablers for enhancing the potential of frugal innovation and to suitably involve customers in the design phase.

3.2 Production system level

Production systems are the core function of every manufacturing company. It can be understood as the production environment of a plant, which defines itself in terms of the available resources, their characteristics, abilities, and composition (Trommer, 2001). Abele (2008) points out, that only a simultaneous adaption or co-evolution of product and production system leads to a successful production for the regional market. An adaption of the product design may affect for example degree of automation, material flow, and assembly structure. Even completely different manufacturing technologies may be applied to produce slightly different product variants at different locations. His approach focuses on strategies, how to adjust manufacturing technologies regarding degree of automation, labour costs, capital costs, technical know-how, and number of variants (Abele, 2008). It cannot be used for identifying cause-effect relationships between product design and production system.

Reinecke et al. (2007) present a method for adapting products to the conditions of global competition, in which product and production flexibility are referred to as key factors of global product adaptation. An integrated product data model, combining functional, process, and component structure serves as the basis of this method. Functional structure contains marketing as well as development views; process structure comprises the attributes production location, material, manufacturing and transportation costs as well as manufacturing and transportation times, while component structure is made up of an assembly-oriented bill of materials. By applying this method improvement potentials and recommendations for product redesigning can be given (Reinecke et al., 2007). However, implications and improvement potentials for production systems are not presented. Große-Heitmeier (2006) presents a method focusing on "globalisation-suitable" product structuring. Besides manufacturing and assembly requirements, technological core competencies are considered. Grauer (2009) developed a methodology supporting production systems planning by considering product design, process organisation, and location factors. Especially product modularisation and necessary manufacturing processes are already regarded in the planning phase.

The presented approaches show, that an integrated design of production systems and regionally customised products has recently attracted research attention. However, the link between regionalisation of product features and corresponding propagation of changes to production systems has not been investigated in a comprehensive way. Accordingly, there is poor consideration of region-dependent product feature evolution in the design process of production systems. Since there is no integrated view on product and production system, there are regional designs for each market, which do not take advantage of standardized modules in the production network for example.

3.3 Production network level

Production in global networks is playing an ever more important role in the light of increasingly globalised sales and procurement markets (Dunning, 1992). Since global networks are exposed to increasing dynamics of the economic environment and changing competitive conditions (e.g. demand/order changes, late deliveries by supplier), global coordination of corporate value added activities is becoming a key factor for success (Permenter and Anand, 2011). Furthermore, production networks can be characterized by their composition of autonomous stakeholders, which influence the overall behaviour with their individual decision-making behaviour (Tapiero and Kogan, 2007). This leads to reciprocal interdependencies, prevailing balance of power, asymmetric distribution of information, and limited cooperation mechanism due to local optimisation strategies of stakeholders (De Miroschedji, 2002). Chopra and Meindl (2009) define four categories of decisions to be made for network configuration, which are interrelated and need to be considered respectively taking the defined network characteristics into account:

- Function of the facility (which role will the plant perform, and which (production) processes will be assigned to it?)
- Location of the facility (plant, warehouse, etc.)
- Capacity allocation (which capacities will be assigned to which locations?)
- Market and procurement allocation (which markets will be supplied by which location, and which suppliers will deliver to which location?)

As the wave of reintegration of formerly outsourced production capacities clearly shows, the decisions have not been properly analysed and evaluated in practice (Kinkel and Maloca, 2009).

For the strategic planning of global production networks for customised products all mentioned decisions have to be considered. Therefore, there are research approaches that explicitly focus on the design, evaluation, and optimisation of production networks. Löffler (2012) presents an approach describing a holistic methodology to systematically design the structure of production facilities and their networks assuring a high degree of changeability. Evaluation approaches, such as presented by Mourtzis et al. (2012), Krebs (2011), as well as Lanza and Ude (2010), provide new methods for the planning of production networks, which often purely focus on site evaluations. Optimisation approaches strongly focus on the product-site-allocation and capacity planning in the production network (Friese, 2008; Chakravarty, 2005). Lanza and Moser (2014) present an approach which includes a multi-objective target hierarchy in their optimisation. Generally, none of the mentioned approaches covers the option to adequately take customised production into account, although studies have addressed the need for more efficient collaboration within a network for providing better customisation options. Tseng et al. (2010) as well as Start et al. (2010) propose collective platforms for improving the collaboration throughout the production networks.

On a tactical and operational level of production network planning there is need for robust production planning and control approaches taking environmental and executional disruptions as well as uncertainties into account (Papakostas et al., 2012). In order to meet planned delivery times and fulfil customer requirements, especially for customized products, manufacturing companies need to react efficiently to changes and disturbances with minimal impact on various stakeholders of their production network. One of the main deficits of existing approaches is that they do not consider short-term constraints and real-time information (e.g. on inventory level, order status, future orders).

3.4 Cyber-physical systems

The term "cyber-physical systems" (CPS) refers to a new generation of systems that integrate computational and physical capabilities to a system that is able to interact with humans in many new modalities (Acatech, 2013). The so called "Forth Revolution of industry" proclaims an irreversible trend towards CPS leading to immense changes in industrial production due to increasing use of ICT-Tools. ICT-Tools can enable manufacturing companies to increase their level of flexibility by using model-based real-time decision-support tools to cope with multidimensional uncertainties and disruptions. They are capable of handling large amount of data as well as high rates of processes existing in future industrial production, characterized by hardly manual controllable complexity (Acatech, 2013). There are first approaches of CPS, e.g. in terms of networked navigation software, which calculate traffic jams from cellular phone data and actual motion profiles to improve route guidance. Another example is the online shop AMAZON, which offers guidance in the order fulfilment process with functions like "Customers Who Bought This Item Also Bought".

CPS can be seen as the next generation of „embedded systems" linking product and production by merging the physical with the cyber world, which opens up new opportunities for production. These systems may for instance support the realisation of robust, distributed production systems by instant rescheduling. Prerequisites are autonomous, self-configuring, knowledge-based sensors, spatially distributed in production systems (e.g. production machines, robots, transporters) and connected to respective planning and control systems. Information about states of all components, machines, and whole production lines could then be collected in almost real-time enabling instant re-scheduling in case of a disruption and hence increasing efficiency and robustness (Lanza et al., 2013). The increase in transparency due to CPS can also allow for integration of innovative visualisation concepts for customer feedback in the design process of customized products enabling the customer to interact with manufacturing companies and suppliers even in the early product design phase. Design changes could be recorded and visualized for future learning and knowledge re-use.

There are several theoretical concepts in current research addressing the question how to evaluate production systems and networks using CPS as enabler. However, further investigation is needed to enable usability of these concepts in an industrial context. Theoretical prediction models are not applicable, because they mostly require specific data, which has to be collected from decentralized databases. The full potential of current state-of-the-art CPS cannot be utilized, because many of them are not ready for shop floor and production network level implementations, as they are not yet supported by interactive tools and effective visualisation capabilities or simply too expensive. The proposed methodology aims at using ICT-Tools for automated evaluation of production systems merging data already stored decentralized in the systems in CPS.

4. Methodology

The main idea behind the proposed approach is to develop a holistic methodology for product-service design for customized / frugal products in dynamic global production networks. This methodology will assist to overcome the stated challenges of manufacturing industry using CPS as key enabler. The development of this new approach is based on three major pillars, namely (i) design of customer oriented products for frugal innovation in a bottom-up development process, (ii) integrated design of product and production systems based on interaction of stakeholders, and (iii) strategic design and operative planning and control of production networks in accordance with local production systems. The three pillars are enabled by innovative cloud-based product lifecycle management (PLM) solutions integrating production as well as customer feedbacks using ICT-enabled methods and advanced multi-objective optimisation algorithms in comprehensive decision support tools.

4.1 Design of customer-oriented products for frugal innovation in a bottom-up development process

As described, frugal innovation and frugal engineering offer high potential for Western companies gaining market shares in emerging markets. But a newly developed frugal innovation oriented product opens up opportunities only if it is attractive for both the provider and the user of the product. Therefore, it has to be designed to generate added value for both parties. That means at first a generic business model will be characterized in detail, also describing the advantages for both parties and the possible conditions for success/failure of the product including a risk assessment. Moreover, a financial model that enables a company to create value from this business model will be developed. Since major challenges are handling of uncertainty and volatility of markets, dynamic multi-criteria scenarios will be defined for the business models.

In order to design a region-specific customer-oriented product by frugal innovation a general analysis of regional market requirements will be conducted. Markets will be analysed in terms of general economic development, growth potential as well as customer requirements regarding frugal innovation for products. If the match between regional market requirement and business model shows potential for customer-oriented products by frugal innovation it can be integrated in a to be adapted Product-Lifecycle-Management-Tool, which has to assure the global coherency of product and possibly related services even if they are limited in terms of features and if they have to be produced in different contexts for different regional markets. These adaptations will be implemented coherently with other variants of Bills of materials (BoM) and Bills of Work (BoW). A feedback process to directly integrate shopfloor and customers during product design enabled by ICT-Tools will also be established.

This online and ad-hoc feedback process will represent a new technological and methodological solution how to integrate customers into development of innovative products increasing transparency for all stakeholders. By establishing standardized mechanisms and protocols to involve customers in the design phase, the customers' influence on future products will increase based on their experience with previous versions of the product. The product designer can directly incorporate this additional information from into the next product version. Additionally, the designer will be enabled to understand implications of product innovations at production system level in real time. Such an approach will close the loop of the customer-driven product design process.

4.2 Integrated design of product and production systems based on interaction of stakeholders

In order to design production systems according to customised products, an integrated platform including a set of tools for (re-)design of manufacturing and assembly systems able to deliver the required system functionality according to the local capabilities will be developed. This represents a significant breakthrough with respect to the traditional time consuming system design procedure embedding several iterations between different departments of the technology and system integrator. The platform to be developed will include knowledge based engineering tools enabling modular design of the system and knowledge re-use, fast system evaluation and optimisation tools to assess the solution's performance as well as advanced virtual and digital manufacturing tools to ensure adequate visualisation of system features to management, shopfloor, suppliers, and customers. Moreover, it will embed product delivery functionality and direct customer involvement in the order-fulfilment process for continuous monitoring of the system's condition.

In order to reach this goal, a knowledge based tool for retrieving and characterizing functionalities and capabilities of existing plants will be developed in a first step. The approach will be bottom-up in the sense that current plant capabilities will be extracted according to the developed knowledge structure. The basic knowledge concerning (i) manufacturing technologies, in terms of their quality capabilities, their degree of flexibility, reconfigurability, and automation as well as (ii) level of workforce skills and competences available will be organized in a knowledge-based repository to be easily accessed through the platform. This knowledge-based repository will be designed to be continuously updated by feeding new data (e.g. collected by sensors and humans) according to technology modifications and new plant designs, with the objective to provide a structured map of capabilities of different production sites to the company management and enabling knowledge re-use for future plant design.

In a second step, a knowledge-based methodology for (re-)design of production and assembly systems will be developed. A set of system engineering rules will be extracted from domain best practices and then formalized and implemented in a user-friendly platform enabling designers to quickly develop first-try system configurations. The macro system design requirements i.e. total production volume and product mix to be delivered, will be taken as input. A user-driven procedure will be designed to guide designers in the definition of macro layout-related decisions and in the selection of the equipment to be allocated within the project. In parallel to this procedure, the cost of the system under design (or the migration costs when re-designing) will be updated to give visibility of offers to designers as well as to customers. All steps of the procedure will be tracked and recorded to enable knowledge re-use and quick solution revisions options.

In order to evaluate redesigned production systems, a three step methodology will be developed in a last step. First, input delivered by the application of the knowledge-based approach will be extended by equipment reliability parameters, usually considered by production system designers, in order to create a performance evaluation tool based on a production flow model and an approximate analytical method to evaluate the main output performance of the system under design. Second, this module will be integrated into a multi-objective optimisation platform to solve a system optimisation problem under multiple and conflicting objectives, including throughput, floor space, cost, energy, and number of resources. Different optimisation algorithms will be tested in order to quickly provide the Pareto frontier, i.e. set of system configurations that are non-dominated, in the sense that none of the objective functions can be improved in value without degrading some of the other objective values. Thirdly, a discrete event simulation tool will be developed to enable verification and validation of robustness of system configurations that populate the Pareto frontier. In this way, consistent evaluation time will be saved with respect to current approaches, which use simulation also in the configuration optimisation phase. The integration of these modules within the system design platform will allow to drastically shortening current extended system design cycles based on continuous interactions between simulation and design departments.

To quickly visualize output of the system optimisation procedure and integrating the described methodology into an overall platform, a virtual reality tool will be developed. Its data and knowledge repository will be connected to a virtual factory manager that will enable direct exchange of data in a bidirectional flow with different digital factory analysis tools. This platform will represent a completely new concept for an integrated design of product and production systems based on interaction of stakeholders. It will be used as an integrated tool to link product, process, and production system information and to provide a globally optimized solution to (re)-design problems. This will not only lead to an increased efficiency in the design phase by connecting it to the production phase but it will also allow for the prediction of effects that a product feature modification will potentially have on the current plant and even the production network configuration by fully considering region-dependent product features in the design of the production system.

4.3 Strategic design and operative planning and control of production networks in accordance with local production systems

Based on the designed production systems the production network has to be designed accordingly. Therefore, a multi-objective optimisation method will be developed to assign standardized product platforms/modules as well as customized and region-dependent product variants to specific plants. According to identified capabilities and frugal product innovation features described in chapter 4.1 the feasible allocation of product modules to potential production sites will be identified first. This defines the feasible search space for subsequent optimisation algorithms to design the production network.

In order to enable the full potential of strategically designed local production systems and global production networks both have to be efficiently planned and controlled on an operative level taking the dynamic business environment into account. Therefore, a KPI based methodology will be developed, which considers main dimensions and characteristics of frugal innovation in order to plan frugal-centred production networks. For this reason a detailed analysis of the production network's actual status will take place, building the basis for a generic modelling approach. Additionally, models and algorithms for efficient multi-objective planning and control regarding optimisation of performance of a production network will be created. Special attention will also be given to a methodology allowing for ad-hoc modification of production networks with minimal effort. These methodologies will be integrated in a decision-support tool, which monitors key influencing factors and provides resulting modification options.

In the next step a tactical/operational concept for a robust global order assignment and local (re-) scheduling in production networks taking multidimensional uncertainties of the business environment into account will be designed. Therefore, related models and algorithms will be developed. The models and algorithms for global order assignment will be responsible for assignment and distribution of real production orders to responsible producers in combination with all required manufacturing details. Furthermore, models and algorithms for decentralized local (re-)scheduling are needed to facilitate the process aiming to meet delivery times or rather to avoid long delays for already assigned production orders. Therefore, they need to be supported by real-time information about rapid changes and disturbances in production networks (e.g. customer demand, order changes, supplier issues, machine breakdowns) to enable proactive reactions on these with minimal ramification of changes. For this reason innovative ICT-systems are to be implemented for the provision and integration of real-time information and end-user feedback. Additionally, a validation and planning environment for "what-if" scenarios for demand and capacity scenarios will be implemented.

As production networks are complex structures consisting of individual actors and involve a series of instructions for part and process, a flow mechanism for information sharing about product and production data between network stakeholders will be designed and assessed. This mechanism will enable a flexible global production network design as well as robust order assignment and local (re-)scheduling in the production network. Additionally, new business models (e.g. contract and financial models) for supporting cooperation and coordination mechanism will be created.

The stated concepts are finally integrated in a decision support system for frugal innovation in production networks, focusing on manufacturing customized products. This decision support system will offer a graphical user interface and a set of web-services ensuring interoperability and seamless integration into the platform described in chapter 4.2. Using customers' feedback via cloud-based ICT tools and open PLM-technology predictive analytics for order-allocation and tactical network planning may lead to a shortened time-to-market taking the technological capabilities of different production nodes and the real loads assigned to plants into consideration. In addition it allows forecasting, planning, and (re-)scheduling of production taking into account effects of customisation on production systems and production networks on an ad-hoc basis in dynamic business environments. This allows a proactive modification of the production network regarding changing conditions with minimal impact on the network. Together with the described PLM-Tool product, production system, and production network can be efficiently balanced between world-wide standardisation and individualized regionalisation.

5. Conclusions

The presented paper is dealing with the issue of planning and control of global production networks whereby the focus is placed on balancing standardisation and regionalisation of product characteristics and production processes taking customer requirements into account. The objective of the proposed approach is to enable globally operating companies to efficiently deliver innovative products adapted to regional requirements regarding product design and functionality. Therefore, a bottom-up development process is presented on how to design customer oriented products for frugal innovation. In addition, an approach for an integrated design of product and production systems has been illustrated based on interaction of stakeholders. This approach is extended by a KPI based methodology allowing for robust global order assignment and local (re-)scheduling taking uncertainties of the business environment into account. With the help of these approaches globally operating manufacturing companies are capable of shortening their time-to-market for customised products and increasing robustness of delivery times at the same time. Additionally, customer satisfaction and loyalty can be enhanced by providing more power to the customer. This may lead to growing customer base and additional sales for the manufacturing company.

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Order-decoupling point and global value network architectures

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Order decoupling point (ODP) decisions have been analysed in operations and supply chain context. Important parameters for decision making include (1) estimated production volume, (2) expected demand variability, (3) cost structure, and (4) lead-time to customer as well as delivery lead-time. By analysing these parameters companies define the right order-coupling point for each product variant. The decision defines lead-times and strategic inventory location. Life-cycle of a product changes optimal strategy. This paper analyses how product life-cycle from ramp-up to maturity and finally to ramp-down in terms of volume affects ODP and how global manufacturing organizations can evaluate order fulfilment strategies.

Keywords: order-decoupling point, global manufacturing, value chain architecture.

1. Introduction

Order decoupling point (ODP) defines the boundary between “push” and “pull” in the supply chain. It defines the location of inventory, whether it is kept in raw materials, components, pre-assemblies, assemblies or finished goods. Order decoupling point decisions are crucial in terms of managing product variety and uncertainty of customer demand. Order fulfilment strategy has become an important part of global value network architecture definition. Manufacturing companies have developed supply chains and networks by moving toward responsive pull based reactive structures and postponing the point of variability in time. Use of product platforms, use of modular structures, built-to-order strategies and late configurations are all examples of decisions related to network level ODP decisions.

Order-coupling points are typically related to product family or process type decision. Based on production volume, fixed costs, operational costs, inventory holding cost and value of lead time for the customer, one can define the order-coupling point for each product variant. These parameters define lead-times and strategic inventory location along the value chain. During the life-cycle of a product the optimal strategy may be changed several times. This paper analyses product life-cycle from ramp-up to maturity and finally to ramp-down in terms of volume and how global manufacturing organizations can evaluate order fulfilment strategies in terms of ODP. Finally, a framework of order-decoupling point and global value network architecture transitions is presented.

2. Literature review

Order decoupling point (ODP) or Order penetration point (OPP) has been defined as a point in manufacturing system where customer order is input. A simplified model of production system includes raw material inventory, work-in-progress for components and finished good inventory for completed products. Engineering work prior to raw-material purchase can be added in the material flow diagram as a separate phase providing product designs. (Figure 1)

Wouters (1991) was one of the first authors to point the strategic importance of customer order decoupling point as definer of lead-time and inventory levels. Giesberts and Tang (1992) recognized very early that hybrid strategies are needed due to changing production situations and combined situations take place very often. Authors such as Wikner and Rudberg (2005) have extended the concept from manufacturing towards engineering and more complex supply chains.

Order decoupling point defines the push and pull boundary. According to Olhager (2010) Customer Order Decoupling Point (CODP) is an important attribute on design and strategic planning. Holweg and Helo (2014) used order decoupling point as one of the defining parameters in value chain architectures, as it defines customer lead-time as well as point where inventory will be held in the value network. Figure 1 below illustrates assembly-to-order (ATO) type of order decoupling point that defines the point where inventory is held. Material flow is pushed according to demand forecasts to this point and demand pulls goods from the assembly.

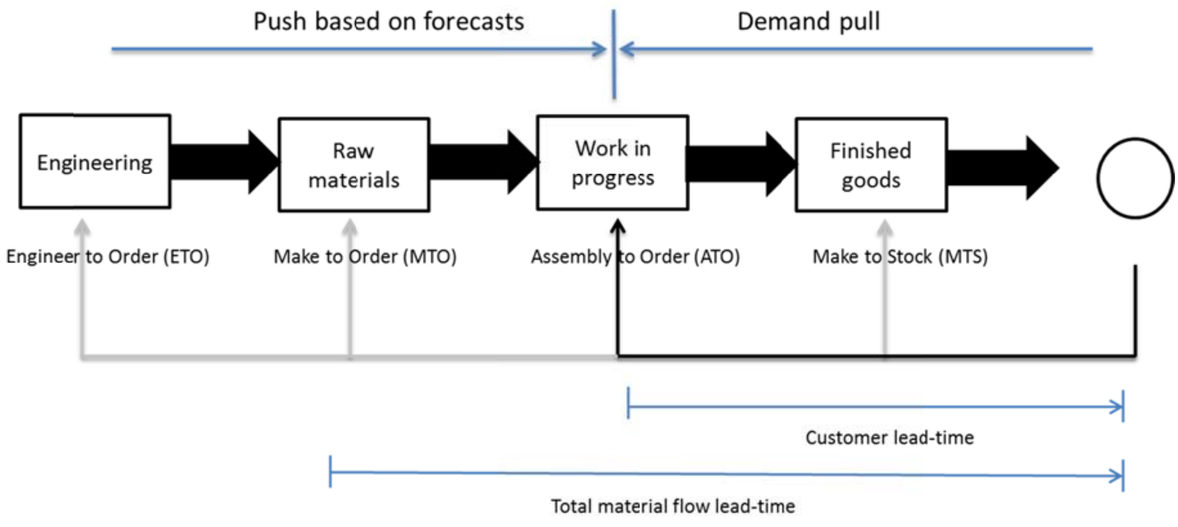


Figure 1. Order-decoupling point example – assembly-to-order operations.

Organizations have different approaches on order-decoupling point. Business strategies and production planning techniques define the push and pull boundary. Strategies for optimal positioning have been presented by Olhager (2003) from business management point of view. Rudberg, and Wikner (2004) presented the customer order decoupling point as a key concept for mass customization strategy. Transition towards pull type of supply chains has been studied by

Van Donk (2001) who analysed food supply chains. Shamsuzzoha et al (2011) proposed a framework for choosing order decoupling strategy for complex products.

Olhager and Prajogo (2012) made a survey on comparing MTO and MTS supply chains improvements. They concluded that MTO firms exhibit impact of supplier integration on performance and MTS firms benefit from internal lean practices and supplier cost cutting. MTS and MTO seem to be different contingencies in terms of development.

The concept of global manufacturing has developed toward global production networks (Shi & Gregory 1998, Ferdows 2008). Graves and Willems (2000) have modelled optimal supply chain inventory location, which takes into account strategic safety stock location. For many businesses the environment is dynamic, products change frequently, demand fluctuates and companies need to plan the process in value chain or value grid levels (Holweg & Pil 2006). Global companies analyse the environment by considering (1) technology and productivity alternatives (Hardman & Mueller 2006), (2) offshoring strategies (Pedersen 2006) and by taking account the uncertainty and flexibility in footprint decisions (Pergler, Lamarre & Vainberg 2008). This all is possible due to free international trade and global logistics system that is able to move large quantities of freights in low costs (See Stack & Gouvernal 2011).

Shrinking product life-cycles are presenting challenges for many global manufacturing networks. Product life-cycle should match on supply chain strategy (Aitken, Childerhouse, Towill 2003). Many consumer electronics product models are made for a period of a year or less. Fashion industry is using up to eleven seasonal product ramp-ups annually. Combining global value chain strategy and such short product life-cycles requires advance planning on supply chain structure. One attempt to respond on this need has been presented by Shi and Gregory (2005) who proposed virtual manufacturing for fast response global networks.

3. Modelling and analysing

In order to analyse the decision making of choosing order decoupling point of each product and channel, the following parameters should be taken into account: (1) product structure and global value network, (2) production life-cycles, (3) lead-time and inventory mechanism, and (4) transition dynamics between order-decoupling points.

3.1 Product structure and global value network

Physical structures of products are presented as bill of materials. As many industrial products represent actually a product family consisting of large number of possible variants, estimated demand for each component should be evaluated based on expected customer demand information. Cost information for each component and operation may be connected to bill of material and operations location can be connected to each operation phase. Value chain can be analysed by switching different types of locations and factory types for each node (Figure 2).

This results network structure showing how suppliers, distribution centres, factories are connected to sales channels and how KPIs such as delivery lead-time and on-time delivery are being built from the structure (Figure 3).

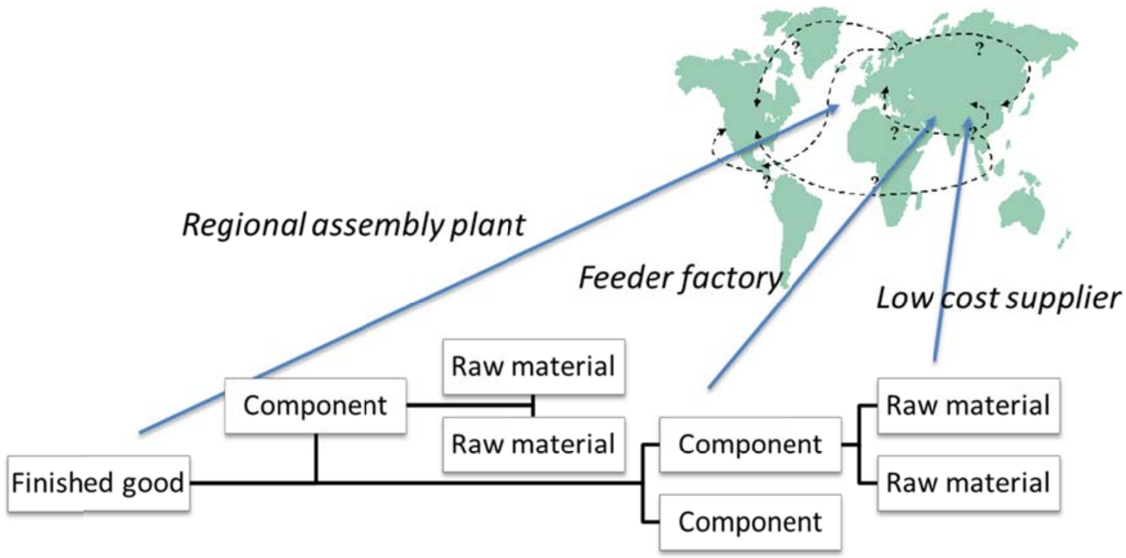


Figure 2. Bill of material example – product variant in global sourcing.

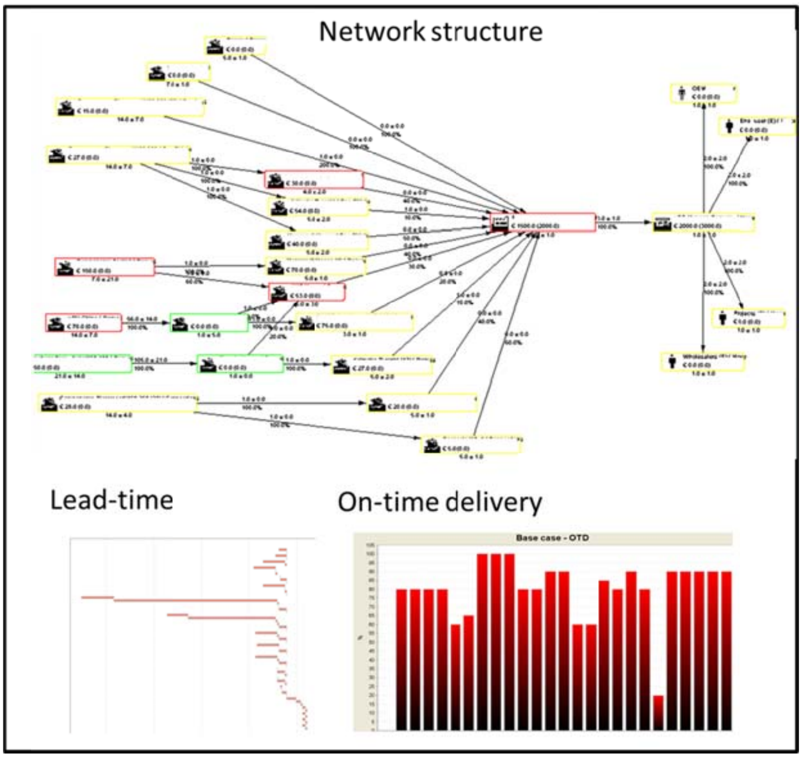
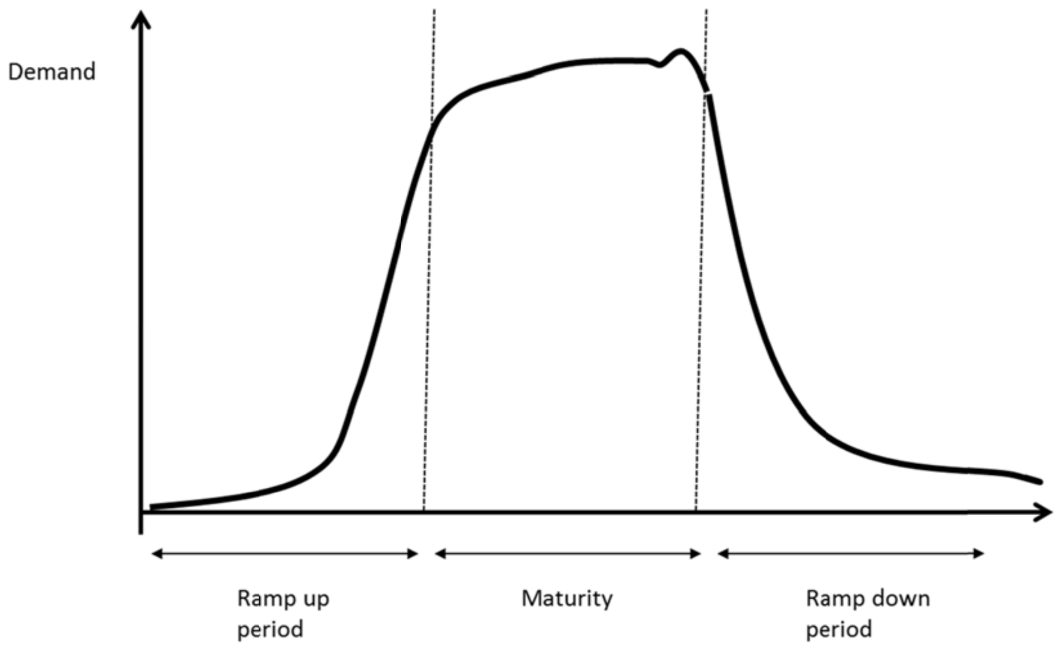


Figure 3. Value chain architecture – combining network structure and performance measurement.

3.2 Production life-cycle phases

Product life-cycle in production may be divided into three main phases: (1) ramp-up, which is the introduction of the product, (2) maturity during the middle of life, when production volumes are at highest level, and (3) ramp-down period during the end of life. Depending on the industry, the actual length of expected product life-cycle may vary between months to decades, but the characteristics of the phases are similar. (Figure 4).

Phase	**Ramp-up**	**Maturity**	**Ramp-down**	
	Beginning of life		Middle of life	End of life



R&D	Frequent communication with production		Updates, product family expansion	Spare part support
Operations	Quality		High efficiency	Support
Learning rate	High		Low	Low
Strategic focus	Learning curve		Cost efficiency	Transition to new products
Lead-time requirement	Longer acceptable Building capacity		Shorter	Longer accepted
Product price	High		Low	Disposal or higher spare part pricing strategy

Figure 4. Stages of product life-cycle.

3.3 Lead-time and inventory

Order decoupling point has a significant impact on what customer perceives as delivery lead-time and how inventory is allocated at each part of the supply chain. Table 1 illustrates how inventory is kept at each strategy and how customer lead-time (LT) is built for a single product variant. When number of product variants is increasing and relative demand for each product variant is lower, inventory holding costs in case of make-to-stock type increase and keeping part of the volume as ATO or MTO becomes more attractive.

Table 1. Order decoupling point vs stock and customer lead-time.

	ETO	MTO	ATO	MTS
Raw material stock	0	1	1	1
Component stock	0	0	1	1
FG stock	0	0	0	1
LT	LT_{eng} + LT_{rm} +LT_{comp}+LT_{fg}	LT_{rm} +LT_{comp}+LT_{fg}	LT_{comp}+LT_{fg}	LT_{fg}

Typically inventory holding cost for each stock type has the following components: Total stock = Cycle stock + Safety stock, TS = CS + SS = $CS = \frac{R\mu}{2}$, where R is reorder point and μ is average demand. $SS = z\sigma\sqrt{R + LT}$, where σ is standard deviation of demand and LT delivery lead-time. Once average inventory level has been estimated, inventory holding cost calculation needs value of goods and interest rate r describing the ratio. This may include factors such as inventory capital costs, storage costs and various risk costs.

3.4 Transition between the categories

Figure 5 illustrates potential dynamic behaviours of order decoupling point of each category. In this figure a new variant is introduced in the production and it is first assigned to an engineer-to-order type of process, at least for the first prototypes or zero-series. Then based on decision the product will be made according to chosen strategy, make-to-order from raw materials, make-to-stock or assembly to order from semi-finished goods. This all depends on estimated production volume, product variety, cost of inventory holding and geographic location. The assumptions between these parameters may change and the optimal allocation may change. Typical transition between categories may include:

- High-volume product type will be moved to make-to-stock in order to improve the product availability for the customers and cutting down the lead-times.
- Make-to-order production is applied for relatively low volume products

- Increasing number of product variants forces company to move toward more responsive strategies and assembly-to-order type or make-to-order type of policies are introduced to certain product groups.
- Global operation strategy assigns feeder factory roles for key components that have high commonality. Regional factories apply ATO principles by keeping key components in stock and customize the product variant based on customer order.

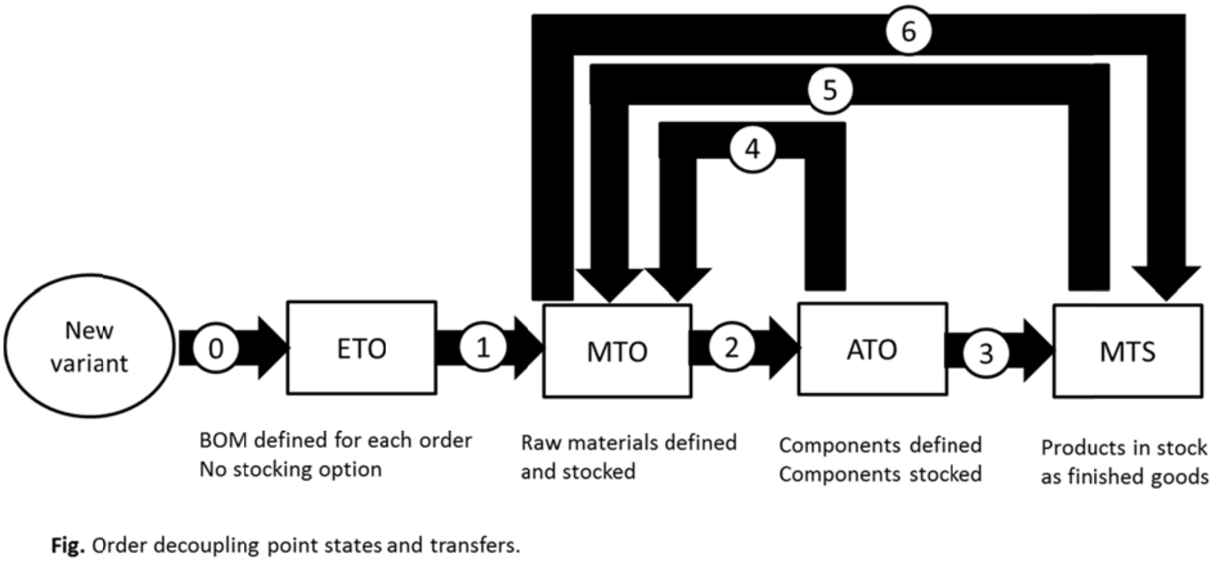


Figure 5. Order decoupling point states and some potential transfers.

4. Problem formulation

An approach to combine the mentioned parameters by estimating d_i Demand for product *i* for time period *t* and combine the following parameters for each product variant:

- LT_i Lead time for product *i*
- LTR_i Customer lead-time requirement for product *i*
- DMC_i Product direct manufacturing cost for product *i*
- IMC_i Product direct manufacturing cost for product *i*
- H_i Inventory holding cost for product *i*

Part commonality for raw materials and components should merge the demands and dampen the required safety stock according to Zinn & Bowersox (1989). Order decoupling point can be selected for each product by defining an optimization problem

Minimize total cost

$$\sum_0^i DMC(d) + IMC(d) + Hi(d), \text{ subject to LTRi} < \text{LTi}.$$

Alternative approach is to maximize profit function for each product by calculating sales price subtracted by cost for each product *i*.

5. Conclusions

Global manufacturing networks shape value chains. Manufacturing and sourcing decisions can be made based on geographical dispersed areas. From supply chain management point of view, order decoupling point is an important decision that has an effect on inventory levels and lead-times. Product life-cycles are short and dynamic changes in ODP decision are needed. Typically the decision making process in operations strategy discusses these points. However, very few quantitative approaches on choosing the right ODP for each product have been presented.

Even each product made in the network may already have been assigned to an optimal ODP type; feasibility of the solution may change over the time, when cost parameters change or number of product variants increase. One approach to consider transitions is presented in Figure 6, which shows areas for MTO/ATO/MTO in terms of relative product demand volatility and customer and production lead-time P/D ratio. This matrix is originally presented by Olhager (2003). Now the adapted version shows proposed possible transitions at different product life cycle phases marked as arrow lines. The figure shows that companies start introduction of a new product typically in the region of high relative demand volatility. During the ramp-up phase the products may end up to high volume with limited number of variability, approaching toward MTS area or toward ATO area in case of increasing product variety during the ramp up. In case of volume expansion, certain variants from ATO may be chosen to MTS area, if the customer lead-time requirements are demanding.

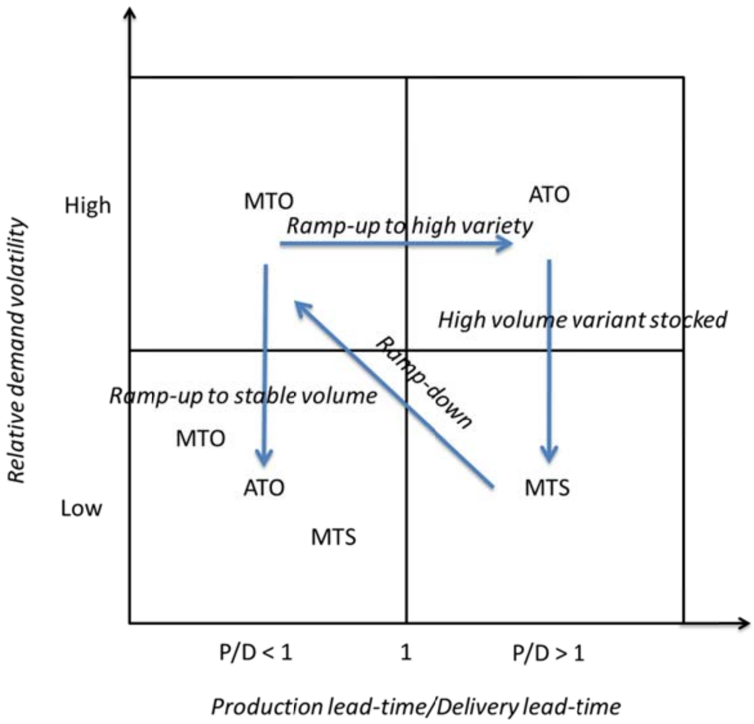


Figure 6. Order decoupling point transitions in demand volatility and P/D ratio matrix (adapted from Olhager 2003).

Companies may have different strategies on expanding the volume by adding variety within the family or being able to stabilize demand variability. The outcomes are different on both of the scenarios. From global manufacturing strategy point of view both approaches may end up to different type of manufacturing footprint. High variety may be assigned to low volume factories and need to operate closely with engineering. High volume-low mix type of product may be more feasible in MTS and low cost country type of sourcing.

In the final part of the product life-cycle it would be typical in ramp-down phase to go back to make-to-order as keeping low volume components would not be financially feasible at different parts of the supply chain.

In order to demonstrate the suggested dynamic behaviour in network level, further work is needed to develop analytical tools. A quantitative approach and systematic analysis tools should be developed in order to analyse various situations and suggest decision support. In addition to approach based on cost minimization, other strategic factors should be considered in the decision-making process. These include the risks related to manufacturing locations and transportation routes, possible tax and custom fees and general sensitivity of the proposed solution.

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Identification of Autonomous Structures in Dynamic Manufacturing Networks using Clustering Approaches

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Abstract
Recent developments in IT miniaturization, wireless technologies, and ubiquitous computing foster new manufacturing paradigms such as autonomously controlled production in decentralized structures. However, the newly created control methods need to operate on existing manufacturing structures. First approaches use clique percolation methods from complex network theory to discover possible autonomously acting clusters in static manufacturing systems. Due to the dynamic change in the structure of manufacturing systems over time, existing clique identification can be strongly biased by the selected size of the observation period of the manufacturing system. We propose a machine learning approach based on clustering, which is able to define autonomous structures in dynamically changing manufacturing systems. Our selected clustering approach is an unsupervised classification technique, which identifies inherent structures present in a manufacturing network based on the modularity of the network. In a first step, we use modularity as a feature that describes collaborative structures. In a second step, this feature is used for clustering coherent network structures with different time horizons to investigate the clustering in dynamically changing manufacturing environments. We apply the clustering approach in an experimental case study on real-world distributed manufacturing systems to illustrate the different results for different periods of the same manufacturing system.

Keywords: autonomous control, clustering, manufacturing systems, dynamics

1. Introduction

The idea of distributed, autonomously controlled logistic and manufacturing processes has already appeared in the second half of the last century (Duffie et al., 1988). The concept then has gained additional interest in the recent years with constant progress in IT miniaturization, sensor technologies, auto-id capabilities, and decentralised control algorithms on the one hand, and an increasing need for flexible and adaptable manufacturing systems in the light of mass customisation on the other hand (Windt and Hülsmann, 2007). A major benefit of this control approach is the reduction of planning and control complexity due to the division of a complex dynamic scheduling problem into many small scheduling decisions in a local environment. This break-up of the complex scheduling problem is usually done by representing shop floor resources and products as interacting agents (MacFarlane and Bussmann, 2000). Up to now, research in this field has strongly focused on technological aspects, i.e. which technologies can be applied to support or enable decentralised manufacturing control, as well as on smart control algorithms, which offer an efficient distributed real-time control of manufacturing processes. However, if manufacturing companies want to switch from conventional, hierarchical control to decentralized control - either completely or for parts of their processes - they are not only required to choose the appropriate technology and control algorithm, but they also have to decide which parts of their processes, i.e. which work systems on the shop floor, will form a group of interacting resources (Vrabič et al., 2012). There has been very little research so far on questions such as: What is the appropriate size of a cluster or 'cell' of autonomously acting work systems? How many of these cells should be formed? When and to what extent is it necessary to restructure these cells upon changes in the product mix or in customer demand?

In this work, we want to revisit the idea of decentralised control with a special attention on the question how companies can assess which parts of their manufacturing environment are particularly suited to form groups of autonomously interacting work systems, and how this is possible with existing feedback data, e.g. form manufacturing execution systems (MES), without additional modelling or simulation activities. The remainder of this article is structured as follows: Section 2 reviews briefly the idea of decentralised control in manufacturing, and the subsequent section examines existing approaches for group identification in manufacturing systems and their suitability for the formation of autonomous clusters. Section 4 presents our proposed machine learning approach for cluster identification including a case study based on real data from a manufacturing company.

2. Decentralised Control in Manufacturing

The concept of replacing a central planning instance for scheduling in manufacturing with decentralised, autonomously acting agents has been extensively studied from many perspectives and under a variety of names: 'Heterarchical Control' (Duffie et al., 1988), 'Holonic Manufacturing' (Brussel et al., 1998), 'Distributed, Intelligent Control' (McFarlane et al., 2003), 'Autonomous Control' (Windt et al., 2008), or 'Intelligent Products' (Meyer et al., 2009). Windt et al. (2008) define the concept as "the ability of logistic objects to process information, to render and to execute decisions on their own." The definition of McFarlane et al. (2003) comprises four characteristics of distributed, intelligent control: (1) control system decisions are determined by more than one decision-making element, (2) the decision-making elements interact collaboratively and flexibly, (3) no complete information for all elements, and (4) decision-making elements are typically linked to physical elements (machines, products, parts and customer orders). From the latter definition we can conclude that there are three elements that make up a distributed control system. The first element is the *technology* that enables the interaction of the single elements (characteristic 2), such as wireless communication, sensors, and data processing, as well as auto-id technology (e.g. radio frequency identification, RFID) that links agents to physical objects (characteristic 4). Secondly, there are the *control algorithms* that determine the decision-making and the collaboration (characteristics 1 and 2). These can be multi-agent systems (MAS) or bio-inspired control approaches. Finally, a distributed control system exhibits a certain *structure* or topology, as it is composed of multiple decision-making elements (characteristic 1), which interact locally, because they do not have complete information (characteristic 3).

The first two aspects, technology and control algorithms, are covered by a variety of research contributions. Some examples for research on technologies are auto-id (McFarlane et al., 2003, Böse et al., 2009) and sensors (Jedermann et al., 2006). There exist a multitude of decentralised control algorithms, from MAS (see, e.g., Shen et al., 1999, for an overview) over phase synchronization (Lämmer et al., 2006) to bio-inspired approaches (e.g., Armbruster et al., 2006), with sometimes similar characteristics (Windt et al., 2010). However, the question of which structures or layouts in a manufacturing system are particularly suited for decentralised control has never been explicitly addressed. Usually, the control algorithms implicitly define how the decision-making entities interlink with each other. Interestingly, Scholz-Reiter et al. (2009) have recognized that decentralised control is not either existing or not, but that manufacturing systems are characterised by a 'degree of autonomous control'. They claim that there is an optimal degree of autonomous control, at which a manufacturing system exhibits the maximum performance. This means that the performance of a manufacturing system is not monotonically increasing with the degree of decentralisation, but there is an optimal configuration as a trade-off between efficient decentralised control structures and high complexity due to excessive interaction. McFarlane et al. (2003) address this relation in their definition when postulating the limitation of information availability for all elements (characteristic 3). However, a concrete approach to determine this optimal degree of decentralisation is currently not available. Even if the optimal degree of autonomous control can be found, it does not offer a solution to the question which parts of the system should collaborate and share information.

Companies that are confronted with a high complexity in their production scheduling due to a high variety in their product portfolio, small batch sizes right up to unique products, and a high variance in processing times might choose to introduce decentralised control on their shop floor. As these companies already have an existing manufacturing infrastructure and might want to test decentralised control in a part of their manufacturing system before migrating the complete system, a complete switch to decentralised control would be too costly and risky. Additionally, a system that is fully controlled by decentralised agents could not be supervised and monitored appropriately by the company management. Even if full decentralisation would lead to a higher performance in the long run, managers are reluctant to completely surrender control to autonomously acting agents. Having smaller groups of autonomously acting work systems, on the other hand, allows management to monitor and understand the control activities inside these groups. Therefore, companies require a straightforward tool to determine which groups of work systems are particularly suited for autonomous collaboration by using existing information. A promising approach is the use of clustering techniques on the interaction intensity of work systems. Companies can easily derive the intensity of material flow between work systems from MES feedback data and use this information to identify clusters of closely collaborating machines. Furthermore, if we split the data in different time slots, we can also consider the dynamically changing situation on the shop floor.

3. Existing Approaches for the Determination of Autonomously Acting Clusters in Manufacturing Systems

3.1. Cell Formation Problem

As indicated earlier, there are almost no approaches directly addressing the problem of the formation of clusters of autonomously acting work systems. However, there is a similarity of this problem to the cell formation problem in manufacturing, although there are differences in the motivation for the cell formation and in the underlying cost functions. We will begin this section with an examination of the relationship to cell formation, followed by a brief overview on an existing procedure for the identification of clusters in the next subsection.

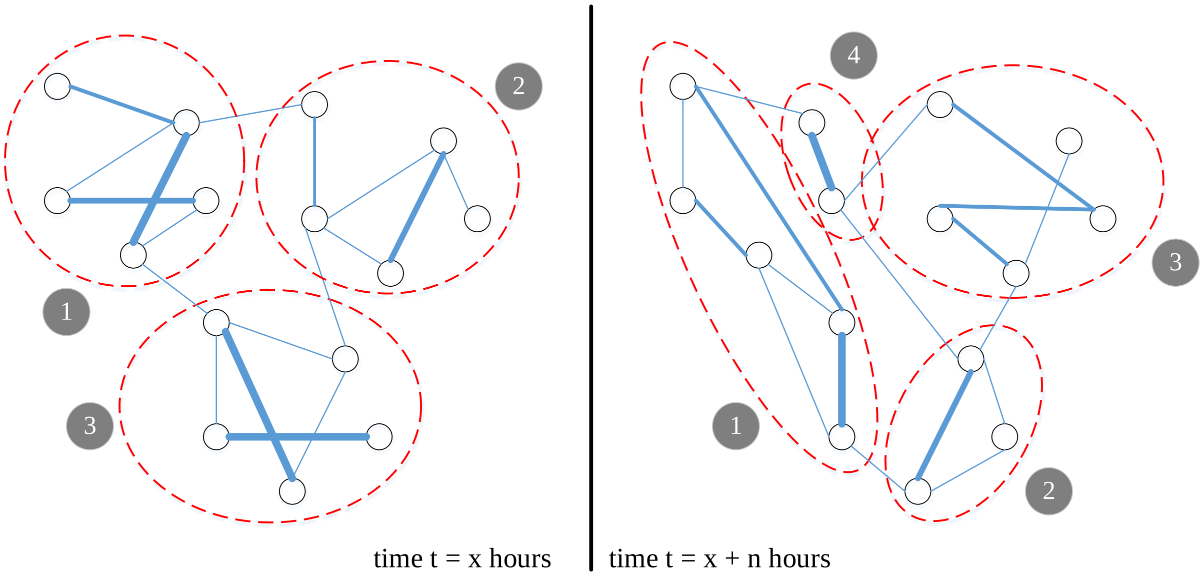


Figure 1. Principle of the dynamic cell formation for a fixed setup of machines in a manufacturing scenario starting from time point *x* over a time span of (*x* + *n*) hours. The material flow (edges) changes over time which results in a dynamic adaption of autonomous machine clusters.

Cellular manufacturing as part of the group technology principle aims at forming cells of work systems on the shop floor in order to take advantage of batching effects such as increased utilization by reduction of setup and transportation times on the shop floor (Selim et al., 1998; Papaioannou et al., 2010). Scientists strive to solve the cell formation problem by identifying similar parts or processes and spatially group the corresponding machines. An overview on the cell formation problem is given in, e.g., Selim et al. (1998) and Papaioannou et al. (2010). The problem of clustering autonomously acting clusters in manufacturing scenarios is a sub-area of an overall cellular manufacturing strategy. In classical cell formation, the time horizon is expected to be fixed, which neglects product variability and a dynamic change of demand requirements. Even dynamical solution approaches to the cell formation problem assume full transparency on past and future events (Tavakkoli-Moghaddam et al., 2005) and are thus not readily suited for building a topology for decentralized control. Figure 1 illustrates the dynamic development of material flow relations in a manufacturing system and the subsequent re-allocation of clusters of interacting work systems.

3.2. Clique Percolation

Vrabič et al. (2012) already pointed out that there is currently no agreement on size and scope of autonomous structures in manufacturing systems. They propose to model a manufacturing system as a network of material flow and to apply the clique percolation method (CPM) from complex network theory (Palla et al., 2005) for the identification of clusters of autonomously acting units. The CPM is a method to identify strongly connected components (sub-networks) in a graph. A so called *k*-clique is a subset of *k* nodes, which are fully connected, i.e. every node in the subset is connected to every other node. The assumption behind this method is that autonomously acting units have a higher degree of *intra*-unit information flow than *inter*-unit information flow. The flow of material is used as a proxy for information flow, because it can be assumed that information about orders is exchanged along with the physical material. Vrabič et al. have carried out a case study with a data set from an equipment manufacturer. They generated a network representation from the data set and present a selection of identified cliques. MES feedback data can easily be transformed into a graph representation: all work systems form the set of nodes. The feedback data has to be sorted by operation start time and grouped by manufacturing order. For every two consecutive operations belonging to the same manufacturing order, a link between the two respective work systems (nodes) is created. If there are multiple material flows between the same nodes, the link is assigned a link weight equal to the number of items passed over.

Although this approach is easy to understand and to apply, it has some major drawbacks. Firstly, the size of the clique *k* has to be chosen in advance, so that the user of this technique has to run the method multiple times for different values of *k* to explore all possible cliques. This results in an ambiguous set of solutions. Secondly, Vrabič et al. realize that if they use data over a very long period (e.g. one year), there are so many links that the number of cliques increases too much. Their solution is to eliminate all links with a weight below the average. This reduces the number of cliques, but the choice of the threshold for link elimination is arbitrary and another parameter to select in advance. Thirdly, the requirement of a cluster of being fully connected is questionable. E.g., if there is a set of 10 fully connected work systems, and an 11th node being connected to only 9 of them, it would be still reasonable to include this node in the cluster. Finally, one of the strongest disadvantages is the possibility that a work system can participate in multiple cliques. Figure 2 shows the result when applying the exact method of Vrabič et al. with $k \geq 6$ to a feedback data set of a job shop for parts for industrial facilities. The majority of clique members belong to multiple groups, so that a clear distinction of the work systems into autonomously acting units is not possible.

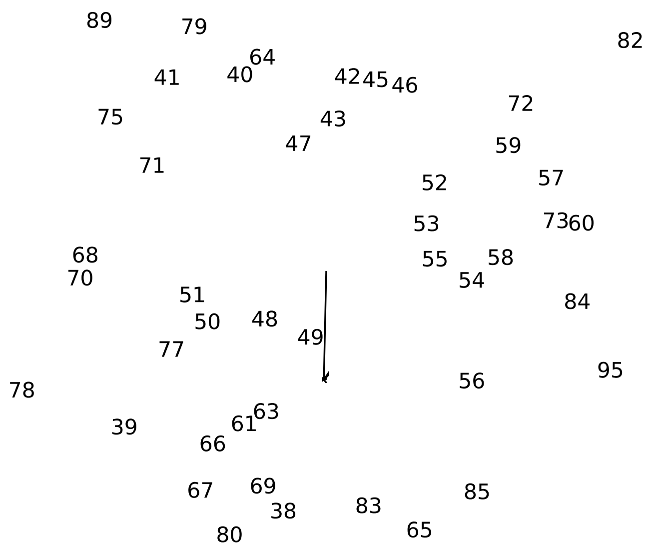


Figure 2. Application of the clique percolation method as described in Vrabič et al. (2012) to a set of feedback data from a job shop manufacturer's MES. The ambiguous cluster allocation of the work systems complicates the interpretation of the result.

In order to overcome the shortcomings of the presented procedure, new approaches need to be developed, which offer the desired characteristics: as few preselected parameters as possible (such as cluster size, number of clusters, thresholds, etc.), as few ambiguity in cluster allocation as possible, and no unrealistic clustering conditions (such as full connectedness). In the following section, we present an alternative approach with fewer restrictions.

4. Cluster Formation Based on Shop Floor Feedback Data

4.1. Modularity based Formation of Autonomous Clusters

Complex manufacturing scenarios results in large network graphs with a huge amount of machines (vertices *n*) and material flows (edges *m*). To overcome the limitations of a fixed number of clusters we adapted the hierarchical agglomeration algorithm for the detection of community structures presented in Clauset et al. (2004) to a cluster formation problem in a real world manufacturing scenarios. A main advantage of this formulation is founded in its linear complexity given by $O(md \log n)$ where d is the depth of the dendrogramm describing the community structure. A standard procedure to divide graphs in communities is an iterative partitioning of the network by a factor of 2. An overview about different methods of top down cluster formation in graphs is given in Newmann (2006). In contrast to top down methods for cluster formation in huge network graphs, the approach used in this contribution initially assigns every single vertex to a separate community. Vertices are merged based on a specific network property in an iterative process.

In this context modularity is used as an indicator to evaluate cluster membership. The modularity indicator will be large for networks with a ‘good’ division into communities, because it measures the amount of within-community edges. Let A be the adjacency matrix describing all possible edges between vertices in the graph G. One single entry of the adjacency matrix A can be defined by

$$A_{ij} = \begin{cases} f & \text{if vertices } i \text{ and } j \text{ connected} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

The number f is a non-zero element in the range of $0 < f \leq 1$ and describes the strength of the connection between vertex i and j. As a convention is this paper we set the diagonal elements of the matrix A to zero to avoid looping edges in the graph representation. Single communities in the graph are denoted by c, where a vertex i belongs to community c_i. The quantity of connections (edges) which describes the number of connected vertices both located in the same graph cluster is given by

$$\frac{1}{2m} \sum_{ij} A_{ij} \delta(c_i, c_j) = \frac{\sum_{ij} A_{ij} \delta(c_i, c_j)}{\sum_{ij} A_{ij}} \quad (2)$$

The denominator in the fraction can be seen as a normalization into an interval of [0;1]. The function $\delta(c_i,c_j)$ is 1 if $i = j$ and 0 otherwise (i.e. it indicates if i and j belong to the same cluster or not), and m indicates the total number of edges within the network. The quantity has its largest value of 1 in the case when all vertices belong to a single community. Indeed this is not a good quantity to describe community in graphs. Therefore, Clauset et al. (2004) subtracted the expected value of the same quantity for a randomized network. In combination with the degree d_i for a vertex i of the network which is defined as

$$d_i = \sum_j A_{i,j} \quad (3)$$

In a completely random network, the probability of an edge between the vertices i and j but with respect to the vertex degrees is given by $\alpha = \frac{d_i d_j}{2m}$. The modularity Q is defined as:

$$Q = \frac{1}{2m} \sum_{i,j} \left[A_{i,j} - a \right] \ \delta(c_i, c_j) \quad (4)$$

In the trivial case of a randomized network, the modularity of the network is 0. Nonzero values denote a structured network with the probability of inner-community edges. Clauset et al. (2004) have pointed out that a modularity value of 0.3 is a good indicator for significant community structures in a complex network. The optimal division into clusters can now be achieved by maximizing Q while varying the cluster allocation c_i for all nodes $i \in \{1, \ldots, n\}$. To speed up the automated division of a graph network in communities, Newman (2004) has introduced a greedy optimization heuristics. The approach repeatedly fuses vertices to communities and optimizes for large values of Q. Based on this technique the optimal number of communities can be determined without explicit knowledge about the number of existing communities. In the next section we describe a case study based on a complex manufacturing network and show the power of the proposed method for a dynamic change of material flow over time.

4.2. Case Study

In this case study we investigated a complex real world manufacturing network. The data has been extracted from the MES of a tool manufacturing company. The manufacturing environment is a job shop, and the majority of the manufactured products are individual orders. The network consists of 51 machines and 3708 different jobs in total. The jobs on the machine are either single jobs, with just one machine included, or a job is distributed over different kinds of machines up to 10 machines per job. Most of the jobs belong to the latter type. Machines in the graphs are represented by vertices and material flow is represented by weighted edges, where high work flow is visualized with thicker edge representations.

To show the potential of the proposed algorithm with respect to the dynamic development of the manufacturing system over time, we divided the manufacturing scenario in different time horizons. A time horizon of 8 hours represents jobs with a duration of a complete work day, 16 hours and 24 hours respectively. Figure 3 shows the basic experimental setup.

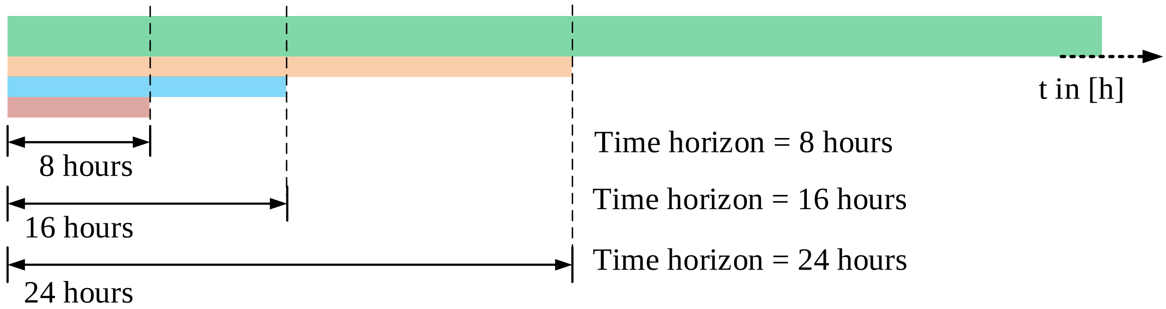
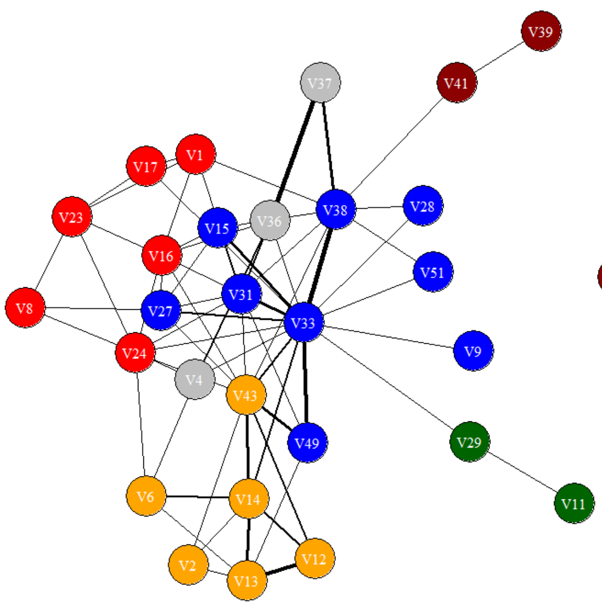


Figure 3. Time horizon for dynamic evaluation of community detection in complex manufacturing networks

Based on a graph representation of the manufacturing network we applied the proposed algorithm for community estimation in graphs. The goal is to extract unique sub-graph communities, which can be treated as autonomous structures in complex manufacturing networks. In contrast to methods described before, this approach does not require any predefinition of cluster sizes or quantities. Figure 4 a) shows the graph for a time horizon of 8 hours. The automatically extracted number of communities is 6 and the machine with the highest amount of incoming and outgoing edges is V33, which also represents the highest workload for this machine with respect to other machines. From a manufacturing point of view, the automated decision of the algorithm is reasonable, because it tends to group machines with high amount of material flow, like Machine 38, 33 and 49.



a) Time horizon 8h b) Time horizon 16h

Figure 4. Resulting graph representation for a work time horizon of a) 8h and b) 16h period. The colours represent the community membership. The time horizon of 8h consists of a total amount of 6 autonomous communities

and the 16h horizon of 5 autonomous communities respectively. Please note that the colours are chosen randomly for different time horizons and do not necessarily represent the same communities in both pictures.

Figure 4 b) shows the communities for a time horizon of 16 hours. The total number of communities is 5, in contrast to the 6 communities in the case of a time horizon with 8 hours. The machine with the highest material flow is machine 36.

In the final experiment the time horizon is set to 24 hours, which results in a graph shown in Figure 5. The total number of communities is 4 and the machine with the highest workload is again machine 36. In contrast to time horizons of 8h and 16h, the machines with ID 11 and 29 are no longer grouped in separate clusters. In the 24h scenario these machines are added to a larger sub-community.

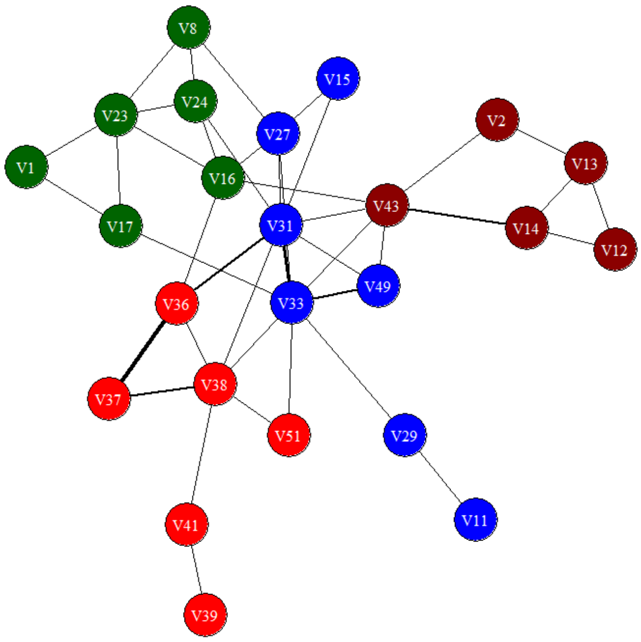


Figure 5. Resulting graph representation for a work time horizon of 24 hours. The total number of autonomous communities is 4.

5. Discussion and Conclusion

In Section 3 we have argued that there are certain desirable properties when clustering a manufacturing network into groups of intensely interacting work systems. Because of the non-deterministic nature of material flow in job shop manufacturing systems, it is important to have a clustering technique that is not constrained by predefined parameters such as number of clusters or cluster size, and that is not based on unrealistic or too strict cluster formation rules, such as the requirement that groups of work systems need to be fully connected. In contrast to existing approaches, our first attempt is not constrained by the above-mentioned prerequisites. It is solely based on the connection strengths between the work systems, indicated by the amount of material flow. This characteristic allows for a clustering of a manufacturing system, regardless any previous knowledge about its composition and the material flow. This is particularly important if we apply the method to varying temporal extracts of the graph, because we are now able to observe the re-distribution of clusters in a manufacturing system in the course of the dynamic development of the material flow.

Our long term goal is to facilitate the application of decentralized control in manufacturing by limiting the amount of required agent-to-agent communication to meaningful subgroups within the complete manufacturing system. A second goal is to identify parts of the manufacturing system where the application of decentralized control is particularly suited due to a high amount of interaction between the work systems, so that companies can iteratively introduce decentralized control to their manufacturing system, starting with the most promising work systems regarding the improvement of overall system performance.

The next steps in our research are the quantification of the quality of cluster selection, accompanied by simulation experiments that test the performance improvement induced by the decentralized control in the identified clusters in comparison to the random selection of clusters or no clustering at all. In a subsequent step, we want to check how the dynamic reallocation of clusters in a dynamically evolving manufacturing system contributes to the performance of the applied decentralized control procedure.

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A Future Supply Chain Assessment Framework: a case study of Terpene-based Supply Chain

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The aim of this research is to adapt existing supply chain analysis techniques to the analysis of compound class defined supply chains in order to explore the key factors that influence the commercial viability of renewable chemicals feedstock's (RCFs). Supply chain analysis has traditionally been applied to product or company defined supply chains. More recent publications have presented examples of source, industry, technology and by-product defined supply chain analyses. However, a clear gap exists in the analysis of compound class defined supply chains. Furthermore, the field of RCFs is receiving an increasing amount of attention due to the potential of RCFs to replace petrochemicals. In particular, terpenes present an example of a RCF supply chain that allows for the study of a compound class defined supply chain. Therefore, an existing supply chain analysis methodology was adapted to the analysis of compound class defined supply chains. The methodology was further extended to include the consideration of environmental and economic factors. The resulting methodology was applied to terpene based RCFs as a case study. This allowed the identification of the key factors that affect the viability of terpene RCF supply chains. This terpene viability framework was extended to support the viability assessment of RCF solutions. The primary challenge to application was the complexity at the market side of the supply chain that appears to be inherent in compound class defined supply chains.

NB: the full paper will be available online following the symposium.

An Overview of Chinese Manufacturing Development in the last Ten Years: to celebrate the 10th GMC Symposium

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1 Purpose

The global business environment has been changing fast in the last decade (2004-2013), during which China's manufacturing also gained dramatic growth. China has overtaken US as the world's largest manufacturer in 2010. However, we should confess that the consequential problems are getting more and more serious and noticeable, such as rising cost, transformation pressure, environmental pollution, excess capacity, etc. Actually, it is a totally new situation that China's manufacturing never faces and we are supposed to tackle it with an overall consideration to both the experience of developed countries or regions and the China's reality. China has stepped into a new era.

In addition, GMC conference which is committed to studies on China's manufacturing will welcome its tenth anniversary in 2014. It is valuable for the conference to have an overview on the following three aspects: 1) what happened and is happening to China's manufacturing in the last decade including business environment, progresses, and troubles; 2) what has been discussed in the conference about China's manufacturing; 3) what should be discussed in the next conferences.

2 Contents

In this section we mainly focus on what happened and is happening to China's manufacturing from different levels of Country & region, institution & policy, inter & inner industry, enterprise level and systematic view.

Country & region: China is under the pressure of FDI outflow and decline. Why? The main reason is that the upstream price is fast rising which undermines the low-cost advantage, such as wage, land, electricity, capital, etc. They either return to developed countries or flow into South-east Asia countries whose infrastructure is getting better. If have a close look we also could find two important things: more FDI is flowing into service sector and the manufacturing's percentage is declining, the other is that the government is guiding FDI from coastal China to middle & west China and the developed areas like Yangtze River Delta region are setting more tough conditions for FDI.

Institution & policy: China is emphasizing less on quantity but more on quality of economic growth which regards protecting environment and improving energy efficiency as the center. That can be observed from China's latest Five-year Plan. Additionally, social development is seriously out of step with industrial development in China which gives rise to labor supply crisis, welfare crisis etc. Other institutions or policies like WTO membership in 2001, nation-wide urbanization etc all are double-edged sword which on one hand provide a more huge market and on the other hand incur challenges such as being accused of dumping, infant industries protection and so on.

Inter & inner industry: China is still weak in high-end manufacturing especially like micro manufacture and distributed collaboration system of design and manufacture which has been a bottleneck. Fortunately some emerging priority industries like clean energy, new energy vehicle, biotechnology, new IT and new materials provide windows for catch-up. Besides, finance and ICT are regarded as two efficient paths for upgrading and transformation which make traditional manufacturing more innovative, cost-efficient, sustainable, and environment-friendly.

Enterprise level: Continuous innovation of products and services is to date the top one challenge for China's manufacturing. We could attribute to at least two determinants: entrepreneurship and R&D. It is sure that business model innovation seems to be more and more important and popular, such as servitization. Another player we can't ignore is small and medium enterprise (SME) which plays a critical role in economic growth. Though resource and capability limitation is still the biggest shortage for SME, some new phenomena like born global and hidden champion are worth of our serious attention.

From systematic view, we propose two perspectives. One is *ecosystem* and the other is *value network.*

3 Suggestions

We had a review of the sessions of each past GMC conference and found some trends in our research topics. We seem to discuss increasingly from network perspective instead of chain. ODI is growing fast and catching more attention than FDI. Firms are no longer satisfied with technology transfer but further attach more importance to knowledge management. Sustainability is being emphasized with industries adopting the concepts of zero emission, green supply chain, smart manufacturing and so on.

China has begun to transform to an innovation-driven economy with the features of smart manufacturing, high-end manufacturing, green production, basic research, business model innovation, customization etc. So we propose that both country and firms have to reassess their competitive advantages. However, in the new era, the top priority for government is to establish an open, just and impartial business environment which could contribute to individual firm's innovativeness and efficiency growth should be the top strategy for individual firm which emphasizes more on knowledge management, innovative resource and capability development.

Are Chinese firms' outward foreign direct investments (OFDIs) a kind of herd behavior? Empirical evidence from an institutional isomorphic perspective

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Abstract

In this study, we examine the legitimacy rationale behind the choice of outward foreign direct investment among Chinese firms from an institutional isomorphic perspective. We suggest that, when under a strong pressure to conform at the regional and industrial levels of the Chinese institutional environment, Chinese firms are more likely to adopt OFDI behavior in exchange for legitimacy. We also examine the joint effect between the state ownership of a Chinese firm and the pressures from the firms in the same industry and region on the Chinese firm's OFDI behavior. We test our hypotheses on a sample of 122 firms in 7 industries during 2008-2012, and we find that Chinese firms are more likely to adopt OFDI behavior when more and more firms in the same region or industry go abroad for investment. However, we find no support for the interaction effect between the state ownership and the pressures from the firms in the same industry and region.

Keywords: Isomorphic pressure; state ownership; OFDI

1. Introduction

Outward foreign direct investment (OFDI) is a process fraught with difficulty and risk for firms (Wu & Chen, 2014). For example, study after study puts the failure rate of mergers and acquisitions somewhere between 70% and 90% (Christensen et al., 2011; Peng, 2012). Chinese firms have particularly poor records in completing the overseas acquisition deals they announce (Zhang et al., 2011). As latecomers, Chinese firms typically lack intangible resources, such as advanced technologies, marketing techniques, established brands (Lu et al., 2014) which are important for firms' OFDI (Dunning, 1980). Yet, Chinese firms take a large step in OFDI (Mathews & Zander, 2007), often adopt high-profile acquisitions as a primary mode (Peng, 2012) and even have a tendency to bid higher (Hope et al., 2011). Why does this interesting puzzle happen?

Prior literature on Chinese firms' OFDI generally supports an economic perspective which underlines efficiency. Luo & Tung (2007) highlight Chinese firms use OFDI as springboard to acquire strategic resources and reduce their institutional and market constraints at home, which help to overcome their latecomer disadvantage in the global stage. These studies contribute substantially to our understanding of the reasons why Chinese firms expand into foreign arenas. However, the pursuit of efficiency maximization may not provide a full account of the reasons underlying the Chinese firms' OFDI decision. Because firms are nested within a highly structured historical and cultural context and make choices which are considered to be legitimate (Christine et al., 2006). As pointed out by Yang (2009), Chinese firms' cross-border mergers and acquisitions (M&As) may be affected by the mimetic, coercive, and normative pressure from external environment. This study is designed to provide a better understanding of how external pressure shapes Chinese firms' OFDI behavior from an institutional isomorphic perspective.

Furthermore, past studies view Chinese firms' OFDI behavior as a series of independent choices that are influenced mainly by institution quality and natural resource of host countries (Kolstad & Wiig, 2012) or government support and industrial structure of home countries (Wang et al., 2012), yet with insufficient attention to the interdependent OFDI behaviors between Chinese firms. Studies by Chan et al. (2006), Ang et al. (2014) and Lu (2002) have suggested that interdependent behavior has significant implications for entry mode choice in foreign direct investment.

This study has two objectives. The first is to identify external pressure sources which may influence Chinese firms' OFDI behavior. Because the experience of related firms can carry relatively greater weight in the decision calculus of a firm than the experiences of unrelated firms (Henisz & Delios, 2001), the firms in the same industry or region may be two external pressure sources. The second is to address the question: the extent to which the interdependent OFDI behavior of other firms in the same industry or region influences the subsequent OFDI decision of a Chinese firm. The impact of the firms in the same industry or region on a Chinese firm's OFDI behavior may not be fixed because of the state ownership. Prior study (Cui & Jiang, 2012) shows that state ownership increase a firm's tendency to conform to, rather than resist isomorphic institutional pressures. We therefore argue that a Chinese firm's state ownership will interact with the pressures from the firms in the same industry and region to jointly influence the Chinese firm's OFDI behavior.

This paper proceeds as follows. The next section reviews prior literature on institutional isomorphic perspective. The following section describes the data and methodology for testing hypotheses. We subsequently present results. The final section includes discussion and conclusion.

2. Literature review

Institutional theory argues that social behavior and associated are anchored in rule systems and cultural schema (Scott, 2005) and emphasizes that legitimacy is important for firms operating within an environment (Mayer & Rowan, 1977). Legitimacy is defined as 'a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions' (Suchman, 1995). In order for a firm to gain legitimacy in its organizational field, it may adopt isomorphic behavior when they face isomorphic pressure from the environment (DiMaggio & Powell, 1983). Therefore, the isomorphic pressures of institutions can influence and constrain the strategic choices of firms (Davis et al., 2000; Lu, 2002).

Institutions theory has been applied in international business research to provide insights into the inter-organizational effects on a firm's strategy choice (Haunschild & Miner, 1997; Greve, 2000; Lu, 2002). Especially, the experience of related firms can carry relatively greater weight in the decision calculus of a firm than the experiences of unrelated firms. (Henisz & Delios, 2001). Close ties between firms lead to strong legitimization of practices (DiMaggia & Powell, 1983). Related firms based on their industry or region of origin have previously been applied to define recognizable populations of organization (Li & Yao, 2010; Henisz & Delios, 2001). A Chinese firm therefore subjects to external isomorphic pressures from the firms in the same industry or region when it makes OFDI decision. First, within the same industry, firms are subject to the similar stakeholders (Porter, 1981). Similar normative pressure from stakeholders will exert influence on firm's OFDI decision. Second, within the same region, firms' OFDI decision will be influenced by the same regional government. As Wang et al. (2012) point out that government support plays a great role when Chinese firms make OFDI decision. In summary, pressures from firms in the same industry or region are two main isomorphic pressure sources influencing the OFDI decision of a Chinese firm.

The institutional perspective also highlights the factors internal to a firm that can impact the institutional processes of the firm (DiMaggio, 1988; Scott, 2005). For firms that are affiliated with external institutions, their responses to external institutions are likely to be a function of the consequences of the political affiliation. State ownership creates the political affiliation of a firm with the government and increases the firm’s resource dependence on the government (Cui & Jiang, 2012). Such resource dependence increases firm’s tendency to conform to, rather resist, isomorphic institutional pressures (DiMaggio & Powell, 1983; Oliver, 1991). Firms with different level of state ownership will vary in response to the external isomorphic pressures.

Based on the aforementioned reasoning, we propose a conceptual model that examines the main effect of the isomorphic pressures from the firms in the same industry and region, and the interaction effect between the state ownership of a Chinese firm and the pressures from the firms in the same industry or region.

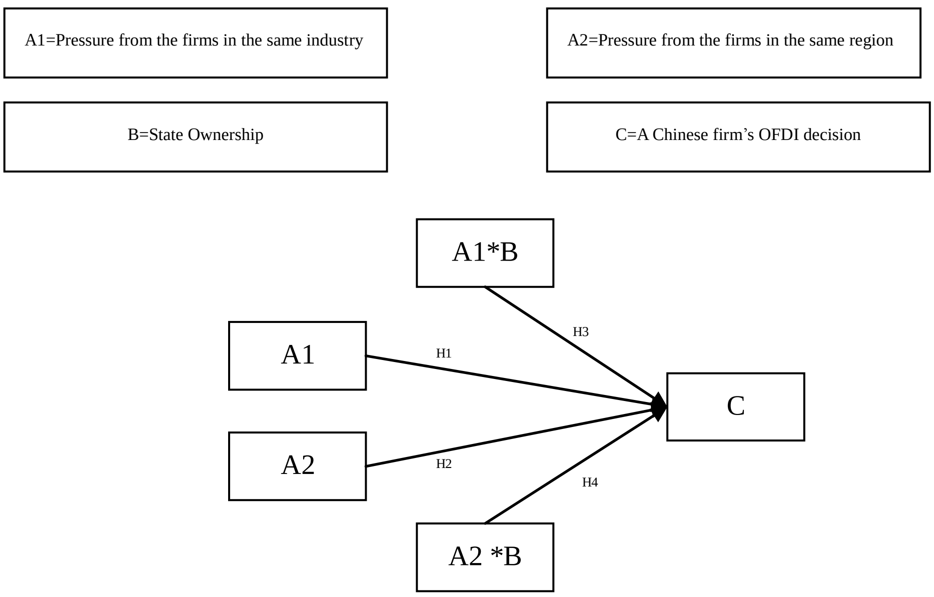

Figure 1 Conceptual Model

3. Hypotheses

Pressure from the firms in the same industry

Industry refers to the group of firms producing products that are close substitutes for each other (Porter, 1980). The experience of related firms in the same industrial context can carry relatively greater weight in the decision calculus of a firm than the experiences of unrelated firms (Henisz & Delios, 2001). If more and more firms in the same industry pursue the strategy of OFDI, they generate legitimacy spillovers about this strategy and the adoption of the OFDI strategy becomes a "taken for granted" approach (Zucker, 1977; March, 1981). Firms can learn from other firms in the same industry, especially those of their competitors to cope with the uncertainty when they go abroad for investment (Henisz & Delios, 2001).

Within the same industry, firms are subject to the similar stakeholders (Porter, 1981). Similar normative pressure from stakeholders will exert influence on firm's OFDI decision. Consumers tend to purchase the products or service from firms which are recognized with strong capabilities or brands. The OFDI behavior can be regarded as manifestation of their capabilities， while firms that do not adopt the OFDI behavior can be perceived as lack of competitive advantage. As a result, consumers may decrease the tendency to purchase the products or services of firms that do not invest abroad, and this can negatively impact on firms' performance. This normative pressure may influence firms' behavior or strategy. In order to avoid falling behind the rivals, a firm may imitate the OFDI behavior which adopted by the firms in the same industry to signal consumers the firm's capability (Lieberman & Asaba, 2006).

Besides that, in uncertain and ambiguity environments, managers are particularly likely to be receptive to information implicit in the actions of others. Such information, although highly imperfect, can have a strong influence on managerial perceptions and beliefs (Lieberman & Asaba, 2006). A manager can be evaluated as a superior type who makes OFDI decision, while a manager who do not adopt a strategy that contributes much to a firm's performance may be regarded as a inferior manager. This normative pressure may influence a manager's decision making. In order to avoid a negative reputation, the manager may ignore their own private information and imitate the OFDI decision of other firms in the same industry (Lieberman & Asaba, 2006), regardless whether the firm really have the ability to go abroad for investment. Thus, the hypothesis is as follows:

H1: the probability of adopting the isomorphic strategy of OFDI will be greater as more and more firms in same industry go abroad for investment.

Pressure from the firms in the same region

It is important to point out that regional institutions play a pivotal role. With 31 provinces, China is well-known for its fragmented domestic economy, regional disparity and considerable institutional variation across regions (Boisot & Meyer, 2008; Mayer, 2008). Provincial governments play an important role in shaping the regional institutional environment (Boisot & Meyer, 2008). This is in part associated with administrative decentralization including fiscal decentralization and the delegation of responsibility for economic performance (Boisot & Meyer, 2008).

Provincial governments are granted authority over and responsibility for economic development in general, and internationalization strategy in particular at the regional level (Wei et al., 2014). There is fierce competition between provinces. In order to develop economy, the provincial governments always grant preferential policy to the firms with capabilities. As a result, firms use a variety of means to manifest their 'capabilities'. OFDI is regarded as a kind of manifestation of firms' 'capabilities'. A firm may adopt OFDI behavior to signal about their own capability and legitimacy when more and more firms in the same region go abroad for investment. If the firms do not invest abroad when they face the normative pressure from the firms in the same region, it may be regarded as lack of 'capability'. Thus, the hypothesis is as follows:

H2: the probability of adopting the isomorphic strategy of OFDI will be greater as more and more firms in same region go abroad for investment.

The interaction effect between state ownership and isomorphic pressure

Although the Chinese economy has become increasingly diverse and plural (Rugman & Li, 2007), many Chinese firms are still stated-owned or state-controlled. The prevalence of state ownership and the variation of the level of state ownership in individual Chinese firms may alter the response of the influence from the firms in the same industry or region.

State ownership creates the political affiliation of a firm with the government, which increases the firm's resource dependence on the government (Cui & Lin, 2012). In order to compete in the world arena, Chinese government including the central or the provincial governments encourages Chinese firms, especially state-owned companies to 'go abroad' since 2001 (Buckley et al., 2007). Chinese firms with high levels of state ownership depend heavily on the government for critical resource input and policy supports (Xia et al., 2013). High dependence can increase the perceived salience of institutional pressure on firms to conform (Kostova & Roth, 2002). An organization is less likely to resist institutional pressure when it is dependent on the institutional constituents that exert pressure (Pfeffer & Salancik, 1978). Acquiescence is the most probable response in this situation (Oilver, 1991). Therefore, compared with the firms with low level of state ownership, the firms with high level of state ownership tend to conform to, rather than resist, the encouragement policy of 'going abroad'.

In sum, the firms with high level of state ownership will be more opt for the isomorphic strategy of OFDI when they face isomorphic pressure from the firms in the same industry or region. Thus, the hypothesis is as follows:

H3: the positive effect of pressure from the firms in the same industry on a firm's probability of adopting the isomorphic strategy of OFDI as predicted in H1 will be stronger for the firm with a high level of state ownership.

H4: the positive effect of pressure from the firms in the same region on a firm's probability of adopting the isomorphic strategy of OFDI as predicted in H2 will be stronger for the firm with a high level of state ownership.

4. Research methods

Sample and data source

The hypotheses were tested using panel data covering 122 firms in 7 industries during 2008-2012. The level of analysis of this study was at the firm level. The final sample consisted of 610 firm-year observations.

Two main data sources were used in this study. First, we obtained raw data on pressure from the firms in the same industry or region from the 'Statistical Bulletin of China's Outward Foreign Direct Investment' which was released by Ministry of Commerce of People's Republic of China (MOC). The second main data source, the annual reports of publicly listed firms in the two stock exchanges of China: Shanghai and Shenzhen, provided data on state ownership, Chinese firm's OFDI decision, international experience and firm size.

Variables and measures

Dependent variable

We gave the dependent variable a value of 1 if the Chinese investing firm had at least 1 project in one year and a value of 0 otherwise.

Independent variables

All independent variables were lagged one year for predicting the Chinese investing firm' OFDI decision. Pressure from the firms in the same industry was measured by the total OFDI flow in the same industry in the previous year. Pressure from the firms in the same region was measured by the total OFDI flow in the same region in the previous year.

To test the interaction effect, we measured state ownership in a Chinese firm as the total percentage of equity ownership by the Chinese government and agencies (Xu & Zhang, 2008).

Controls variables

Both firm size and international experience for each Chinese firm were controlled in the models. Firm size was measured as the number of employees of the Chinese investing firm in the previous year. We used the most common measure of international experience, namely number of years of foreign investment operations outside the home country (Li & Meyer, 2009).

5. Results

Table 1 reports descriptive statistics and correlation coefficients for all of the variables in regression analysis. As shown in Table 1 the Chinese investing firm's international experience and firm size are significantly correlated with its OFDI decision.

Table 2 reports the regression results for The Chinese investing firm's OFDI decision. The fixed effects model is selected based on the result of Hausman test ($chi^2(7)>57.73$, $Prob>chi^2=0.0000$). The dependent variable, the Chinese investing firm's OFDI decision, is a binomial dependent variable. Accordingly, we performed logistic regression analysis to test our hypotheses.

Model 1 includes only the control variables. We find that international experience and firm size are both significant and correctly signed. Model 2 includes the control variables and independent variables. The coefficients for the pressure from the same industry and region are both positive and significant at the level of 0.01, supporting H1 and H2. The direct effect of state ownership was non-significant. Models 3-4 test interactions between the pressure from the same industry or region and state ownership respectively. Both of the coefficients on the interactions in model 3-4 are non-significant. As a result, H3 and H4 are not supported.

6. Discussion and conclusion

Discussion

Chinese firms are becoming important participants in the global economy. And the results of this study tend to confirm that the Chinese firm's OFDI decision is influenced by isomorphic pressure, specially, the pressure from the peers in the same industry or region. Within the same industry, firms are subject to the similar stakeholders. Especially, they try to meet the customers' expectations and the top management of these firms also eager to manifest their capabilities. Under these kinds of normative pressure, the firms may imitate others and ignore their own private information. As a result, the Chinese firms tend to adopt OFDI behavior which is regarded as a way to manifest their capabilities.

In our study, we find no support for the interaction effect between the isomorphic pressure and the firm's state ownership level. Because our research sample does not include the state firms which are affiliated with the central government. Compared with these firms, the firms affiliated with the provincial governments have more autonomy and their strategic decisions are less influenced by the government.

Several limitations of the study suggest promising areas for future research. First, our sample include only publicly listed firms. Future research can extend this study with more firms including listed and non-listed firms or with firms affiliated with central government. Second, we measure state ownership as a continuous variable. The measure has limitations, as it does not capture certain qualitative differences in firm ownership structures. Third, as for all quantitative empirical research, this study has limitations in its ability to fully reveal the processes behind statistically significant relationships. Our data do not allow us to fully disclose the interaction among firms in the same industry or region.

Conclusion

The key finds of this study suggest that Chinese firms are more likely to invest abroad when peers in the same industry or region have already done so. And the trend will not be changed regardless of the Chinese investing firm's level of state ownership.

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The Motivations and Practices of MNCs' Overseas R&D Activities: A Comparative Analysis

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Abstract:

There was a strong movement for multinational corporations (MNCs) from developed countries to establish a transnational configuration of R&D in other developed countries in the 80s and 90s, and in emerging countries such as China and India in the new millennium. These trends have been well documented in the R&D internationalisation literature. That said, MNCs from emerging countries such as China, are trying to move up the value chain, and one important route to do this is by focusing on R&D. R&D operations from emerging countries are expanding their geographic reach to developed countries. In spite of this growing trend, academic research in this field has not kept pace. To what extent are opportunities and challenges of managing R&D different in these countries from those in the west? This paper tries to tackle this question by incorporating the existing literature and practices of international R&D, and compare and contrast it with the current practice of overseas R&D activities by MNCs from emerging countries. A comparative framework is developed to serve this purpose. Drawing on the analysis we suggest that MNCs from emerging countries should learn from the experience of their western counterparts, but more importantly, the unique challenges and capabilities should be considered in managing their international R&D strategies and decisions.

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Keywords:

Multinational corporations; Overseas R&D; Motivation and Practice

1. Introduction

China, as the world's second largest economy, has the most dynamic and fast growing market for both foreign and domestic companies. It is now the hot spot for every multinational company (MNC). In face of the fierce competition from their Chinese counterparts, one way for western companies to respond is to develop products tailored to the local demand. This can be done in two ways: localisation of products designed for western markets, or new products developed specifically for Chinese market. Both of which require a strong presence of research, develop and design capabilities locally. This might explain the growing number of R&D units invested by MNCs in China. However, previous research on international R&D usually focus on large MNCs from developed countries internationalise R&D to another developed country, usually between the U.S., Europe and Japan (Florida, 1997,Asakawa, 2008). Only in the last decade, with the structure change in China's policy (e.g. entry to WTO) and economy, western companies start to explore China as a destination for R&D investment (von Zedtwitz,2004). Within this ten years, numerous multinational companies have setup their R&D units in China. According to UNCTAD (2005), China as a destination for R&D is more attractive than the U.S.. A recent report estimates that there are about 1600 foreign R&D units in China (Financial Times, 2012), usually concentrated on the big cities such as Beijing and Shanghai (Sun and Wen, 2007; von Zedtiwitz, 2004).

In the meantime, It is also worth noting that Chinese companies are supported by the government's "going out" strategy, which encourages Chinese companies to play a part in international capital market and invest overseas (Hong and Sun, 2006). Chinese companies such as Huawei, Lenovo and Haier are now operating in a global scale in all the value chain activities (R&D, production and sales). Earlier research however, mainly focus on Chinese companies' FDI from a macroeconomic level(e.g. Yao, 2006). Very little research has been done in investigating in detail the characteristics of China's R&D activities overseas. This may be because R&D is an universal function and therefore less location specific (Motohashi, 2012). We argue that while numerous papers have addressed R&D internationalisation, they are mostly based on evidences and experiences from western MNCs. If we can acknowledge the differences between Chinese and western MNCs, one might argue that Chinese companies might behave differently from their western counterparts.

To address the gaps in both academic research and practical need, we propose to investigate the following questions:

1) Why do Chinese MNCs conduct R&D overseas?
2) How is the R&D location selected and premise established?
3) What are the unique challenges for Chinese MNCs managing R&D out of China?

Western MNCs have been practicing R&D in China for decades. The challenges and barriers they have encounter in China might be similar to Chinese companies extending R&D to the west, as these challenges and barriers are caused by the same contradiction: the differences in economic system, developing speed, size of the market and technological innovation capabilities. We believe it is worthwhile to compare and contrast the difference of international R&D activities sponsored by western and Chinese companies, and it may leads to fresh insights.

In response to the research questions, we selected six cases (Eisenhardt, 1989;Yin,2003) to study R&D units that were set up by companies from Europe and China.

2. Literature review

Two waves of international R&D activities have been captured in the literature. In the first wave, MNCs from developed country invest R&D aboard looking for new technology or complementary assets that can maintain or further their global competitiveness (Buckley and Casson, 1989; Florida 1997). These R&D investment activities normally happen between two industrialised countries. With the uprising of developing countries such as China and India, the second wave of international R&D concerns about the R&D investment from developed countries to developing countries. The strategic intention is to leverage the technological advancement in MNCs' home countries to the host countries where technological capabilities are relatively weak (Asakawa and Som, 2008;von Zedtwitz 2004). In recent years, especially after the financial crisis, international investment from Chinese companies are starting to grow, among which R&D investment are also included. This can hardly be labelled as a third wave as it is not a global phenomenon yet. But for Chinese firms, overseas R&D investment is a very important route for acquiring technology that could help them compete in both domestic and foreign market. We will review the R&D internationlisation literature from four perspectives: motivations and location choice, organisational structure and managerial issues.

Motivations and location choice

In an early attempt to address the objectives of international R&D activities, Bartlett and Ghoshal (1990) provide a topology based on the original location of innovation and the location of product market. Two typical models are: "centre-for-global", that is to create a new product or process at home country for a global markets, and "local-for-local", which refers to local subsidiaries create their own innovation in respond to the needs of the local demands. Two other models are "locally-leveraged", in which innovations are developed locally for global use, and "Globally-linked", in which globally networked R&D units collaboratively develop products or process for the world market.

Kuemmerles (1997,1999) suggests a simpler but widely cited classification. He distinguishes "home-based-augmenting" R&D units with the objectives of transferring locally created knowledge to a central R&D unit, from "home-based-exploiting" R&D units that transfer knowledge created in the central unit to the overseas unit.

Bas and Sierra (2002) propose four locational strategies based on a firm's existing capabilities and home/host countries technological profile. The first strategy is "technology seeking":A company can invest R&D in a host country with proven strong technology capabilities to offset the home country weakness; The second strategy is exact the opposite, the asymmetry of technological capabilities is reversed and MNCs use "home-base-exploiting" strategy to exploit their advanced technology in a region weak in the field. The third strategy is "home-base-augmenting", in which both home country and host country are strong in a technological field and R&D activities in the host country are set to follow technology development or acquire complementary capabilities. The fourth strategy is "market seeking". The main driver is not the advancement of technology in home or host country but an international expanding option.

The decision of selecting a particular location for overseas R&D units usually involves higher management, R&D department and strategy department (von Zedtwitz and Gassmann, 2002). These motivational factors can be classify into six categories (Gammeltoft, 2006): market-driven, production-driven, technology driven, innovation-driven; cost-driven and policy-driven. Table.1 provides a detailed description of Gammeltoft's classification. Table.2 adopts Gammeltoft's classification to summary motives for R&D internationalisation in the literature.

Table.1 Motives for R&D internationalisation (Gammeltoft, 2006)

Motives	Activities involved
Market-driven	Exploit existing company-specific assets more widely; motivated by market size and proximity; support local sales, closeness to lead customer, improve responsiveness in terms of both speed and relevance

Production-driven	Supporting local manufacturing operations
Technology-driven (pull)	Tapping into foreign S&T resources, technology monitoring (especially competitor analysis), acquire/monitor local expertise, knowledge and technologies
Innovation-driven (push)	Generating new company-specific assets; attaining a faster and more varied flow of new ideas, products and processes; capitalize on location-specific advantages through an international division of labor between R&D labs
Cost-driven	Exploiting factor cost differentials
Policy-driven	National regulatory requirements or incentives, tax differentials, monitoring and exploitation of regulations and technical standards

Table.2 A comparison of motives found in the literature

Motives	General international R&D	Foreign R&D in China	Chinese R&D in west countries
Market-driven	Cantwell and Mudambi (2005); Gammeltoft (2006); Gassmann (2002); Gerybadze and Reger (1999); Kuemmerles (1997);Le Bas and Sierra (2002); Patel and Vega (1999); von Zedtwitz and Gassmann(2002);	Gassmann and Han (2004); Motohashi (2012); Schanz et al.(2011); von Zedtiwitz (2004)	Diminin, Zhang and Gammeltoft (2012);
Production-driven	Gammeltoft (2006); Gassmann (2002); Le Bas and Sierra (2002); Patel and Vega (1999); von Zedtwitz and Gassmann(2002);	Gassmann and Han (2004); Motohashi (2012); von Zedtiwitz (2004)	
Technology-driven (pull)	Gammeltoft (2006); Gassmann (2002); Gerybadze and Reger (1999); Kuemmerles (1997);Le Bas and Sierra (2002); Patel and Vega (1999); von Zedtwitz and Gassmann(2002);	Gassmann and Han (2004); Motohashi (2012); von Zedtiwitz (2004)	Diminin, Zhang and Gammeltoft (2012);
Innovation-driven (push)	Cantwell and Mudambi (2005);Gammeltoft (2006); Gassmann (2002); Gerybadze and Reger (1999); Kuemmerles (1997);Le Bas and Sierra (2002); Patel and Vega (1999); von Zedtwitz and Gassmann(2002);	Schanz et al.(2011)	Diminin, Zhang and Gammeltoft (2012);
Cost-driven	Gammeltoft (2006); Gassmann (2002); von Zedtwitz and	Gassmann and Han (2004); Motohashi	

	Gassmann(2002);	(2012); von Zedtiwitz (2004)
Policy-driven	Gammeltoft (2006); Gassmann (2002); von Zedtwitz and Gassmann(2002);	Gassmann and Han (2004); Motohashi (2012); von Zedtiwitz (2004)

Policy-driven motives are also important in a context of R&D in China (von Zedtwitz,2004). Locating R&D in China particularly in Beijing is important to keep continuous communication with the Chinese government and standard shaping bodies. For example, one important motivation for telecommunication companies to operate a Beijing R&D centre is to be involved in mobile telecommunications standard setting activities by the government (Motohashi ,2012).

Reducing cost is a strong motive for MNCs perform international manufacturing. It is also a reason for foreign firms to do R&D in China (Gassmann and Han,2004; Motohashi, 2012; von Zedtiwitz, 2004). This is later discussed in the case studies that it is not cheap to do R&D in China, especially with limited number of experienced research staffs.

Organizational structures of internationalized R&D

Argyres and Silverman (2004) summarise three types of R&D organisational structure in large firms. A centralised structure that one central R&D report directly to the HQ; A decentralised structure that research is conducted exclusively within division or business unit; and a hybrid structure that combines both features. Centralised structure might allow companies to exploit economics of scale, scope and knowledge spill-over from research projects, whilst decentralised structure might allow firms to enjoy efficiency created by improved information processing and reduced scope of managerial opportunism.

Von Zedtwitz, Gassmann and Boutellier (2004) take a step further and try to identify a set of underlying determinants of the degree of decentralisation of R&D projects and put forward four determining attributes of the project involved: (1) type of innovation: incremental versus radical; (2) nature of the project: systemic versus autonomous; (3) knowledge mode: explicit versus tacit; and (4) degree of resource bundling: redundant versus complementary. They then argue that radical innovation, systemic project work, prevalence of tacit knowledge and the presence of complementary resources requires a more centralised approach, while incremental innovation, autonomous project work, prevalence of explicit knowledge, and the presence of redundant resources is compatible with a more decentralised approach.

Based on the location of research and development functions, four types of R&D operational structure are identified by von Zedtwitz and Gassman (2002, figure.1).

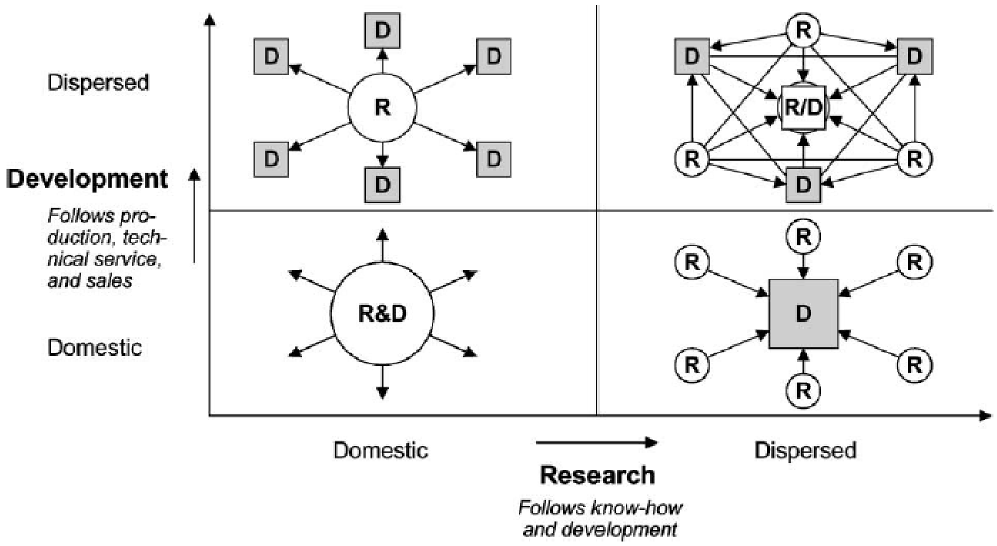

Figure.1 Organizational structures of internationalized R&D (von Zedtwitz and Gassman, 2002: 575)

From a knowledge management point of view, Birkinshaw (2002) distinguishes research units by the types of knowledge involved in the activities. First is self-contained R&D centres, with knowledge assets that are high on observability and low on mobility; second is modular centres with low oberservability and high mobility assets; the last one is home based centres, with knowledge assets low in both observability and mobility. He then suggests that the structure R&D networks is also related to the knowledge type: 1)loosely-coupled network with low knowledge mobility, and 2) integrated network with low knowledge observability.

Practical issues related overseas R&D management

von Zedtwitz and Gassmann (2002) examine the main challenges in establishing an international R&D unit and conducting transnational R&D projects. One significant barrier for companies performing international R&D is the physical distance among R&D units. Compared to local R&D project, international R&D projects need more efforts in communication, coordination and information exchange. The separation of R&D units might cause not-invented-here syndrome and compartmenlisation within the company's R&D functions. It is also difficult to create a coherent working culture, exchange tacit knowledge and build trust in the distanced R&D unit.

In addition to the communication and coordination problems caused by physical distance, several issues have been identified in managing a R&D unit away from homeland. These issues include:

- Managing culture diversity (Gassmann, 2002; Gassmann and Han,2004; von Zedtiwitz, 2004)
- Recruiting, training and retaining of managers and employees (Gassmann, 2002; Selmer, 2002; Kim and Oh, 2002; Gassmann and Han,2004; von Zedtiwitz, 2004)
- Creating synergies with other R&D units (Gassmann, 2002; Yang and Jiang, 2007)
- Retention, integration and utilisation of dispersed know-how (Birkinshaw,2002; Gassmann, 2002; von Zedtiwitz, 2004)
- Protecting intellectual property (Quan and Chesbrough, 2010; Yang and Jiang, 2007; Zhao, 2006; Gassmann and Han,2004)
- Government bureaucracy and lack of transparency (Gassmann and Han,2004)

3. Methods

Due to the explorative nature of this study, we use case analyses of six international R&D practices between Europe and China to illustrate different growth paths adopted by the case companies. Table.3 and Table.4 summarise the characteristics of these companies involved in the international practices. The companies are ensured confidentiality in the interviews therefore they are disguised until formally approved.

Table.3 A summary of overseas R&D units set up by European companies

European company	LifeStyle	Mechanic	BodyGuard
Product market	Consumer electronics	Mechanic components	Electronic products
Annual turnover (US dollars)	30 billion	10 billion	1 billion
% of sales from China in 2013	32% in Asia/Pacific region	24% in Asia/Pacific region	Less than 5%
Headquarter	West European country	Scandinavian country	Scandinavian country
Global R&D network	U.S, Europe and Asia	U.S, Europe and Asia	China only
R&D location in China	Shanghai	Shanghai	Shanghai
Production location in China	13 manufacturing sites in China	Multiply locations	Outsourced to Chinese manufacturers
University Collaboration	Top universities in Shanghai and Zhejiang	Top universities in Beijing	None
Year Setup in China	2002	2010	2013
Size of the R&D unit	110 employees	40	N/A
Entry method to China	Greenfield	Greenfield	Greenfield

Table.4 A summary of overseas R&D units set up by Chinese companies

Chinese company	Messenger	Thomas	ShopSafe

Product market	Telecommunication	Transportation	Electronic equipment
Annual turnover (US dollars)	30 billion	1 billion	60 million
% of sales from overseas	65%	N/A, mainly Chinese market	89%
Headquarter	Southern China	Mid China	East coast China
Global R&D network	U.S, Europe and Asia	Only one	Only one
R&D location in Europe	UK	UK	Italy
Production location in Europe	Eastern European country	UK, belongs to the acquired company	None
University Collaboration	With multiple UK universities	None	None
Year Setup in Europe	2010	2008	2011
Size of the R&D unit	300 R&D staffs	40 R&D staffs	Not disclosed
Entry method to Europe	Acquisition	Acquisition	Acquisition

The cases we selected are all in manufacturing sectors. This is because manufacturing companies are the main source of global R&D activities (**references needed).** This is especially true for international R&D activities conducted by Chinese companies, as most of the recoded data are in the manufacturing sector **(reference needed)**. A practical factor worth mentioning is the accessibility to these companies.

We developed a semi-structured interview protocol focusing on the location choice, R&D network, R&D output and strategic objective of these overseas R&D units. We conducted interviews with top management team members, director of research or senior managers. Half of them had personally involved in the initial setting up process. In addition to interviews, companies' annual reports and other public available information were collected to triangulate the information provided by the informants. Table. 5 shows a list of informants.

Table.5 A list of interviewees

Company name	Interviewees
LifeStyle	Director of China research centre, business director in research in HQ, strategy director in research in HQ and Program manager
Mechanic	Innovation manger
BodyGuard	Director of business
Messenger	General manager of foreign branch
Thomas	Based on public available interview data
ShopSafe	President, CTO

4. Cross-case analysis

Table.6 and Table.7 present the comparison of motives, location choice factors, entry mode, performance and management issues of the 6 case companies, followed up by a comparative analysis.

Table.6 Comparison across European companies

	LifeStyle	Mechanic	BodyGuard
Main motives	Market driven "LifeStyle at that time has big factory of optical storage in Shanghai, so the topic was chosen... semi-conductor division has big activity in Shanghai... so that was the reason to chosen to be able to connect to those" ---- Director of research in China	Market driven "bringing innovation and technical knowledge closer to customers in Asia to better meet local customers' needs" - Company report	Market driven "...we had a little sales in China, but we have to be there to understand customers" - Director of Business
Location choice :main decision factor	Operational efficiency "...reason for that was the headquarter was in Shanghai and most business were in Shanghai, you like to be close to them." - Director of research in China	Support business "There are several candidates... we take into consideration many different factors...close to the plants and customers are the key factors." ---Innovation manager	Operational efficiency "...because we already have a office in Shanghai "
Entry method	Greenfield	Greenfield	Greenfield
Current performance	Number of employee grows from 15 to 100.	Just moved to the new R&D building.	Just set up
Management issues	Research support from the government "If we applied for participating in Chinese national programmes. We never succeed, none of the internationals succeed. Then we found we were not treated equally" --- Director of research in	Operational cost "At the beginning, we did want to leverage the cheap labor in China, but the reality does not justify this motivation. We starts to measure the cost versus efficiency /productivity and the value created"	N/A

China	---Innovation manager

Table.7 Comparison across Chinese companies

	Messenger	Thomas	ShopSafe
Main motives	---Innovation and technology driven "By acquiring us and integrating the company's R&D team into Messenger's own research team, Messenger's optic R&D capabilities can be significantly enhanced" -CEO of acquired company "...the UK is at the forefront of developments in wireless, multimedia and advanced communications" --- CEO of UK branch	---Innovation and technology driven "Particularly they want to invest technologies and facilities we have here, so we would become a leader in technology" - CEO of acquired company	---China-market driven "We want a product that can upgrade our market position" - President of ShopSafe
Location choice :main decision factor	By acquisition, not much location decision involved	By acquisition, not much location decision involved	By acquisition, not much location decision involved
Entry method	Acquisition, all R&D staffs are kept in the centre.	Acquisition, all R&D staffs are kept in the company. "The strategy Thomas discussed with us is to retain our operation here" - CEO of acquired company	Acquisition, all staffs are kept in the company. "Buying the company is a very quick decision. I see the opportunity and we happen to have a lot of cash." - President
Current performance	Aggressive growth "The acquired centre has 50 R&D staff in 2012 and we want to boost the number to 300 by the end of 2015." --CEO of UK branch	Moderate growth With financial support from Thomas, the acquired company invested a new R&D centre. The R&D personal increased from 12 to 40 in 2013. The acquired company also expanded to new market areas with the help of Thomas.	Under expectation "This new product technology and sales channel are very different from our own business, we are struggling to convince retailers to use our products....It is the first foreign company we have acquired...I would think it as a

			learning process" - President
Management issues	The centre will be mainly dedicated to Messenger's R&D priorities. "We expect all contracted projects to be completed and current customers are being assisted to find alternative source of supply" - CEO of acquired company	High autonomy "They give us a high degree of autonomy, and they did not place a Chinese manger at the top after acquisition"- CEO of acquired company	High autonomy "We acquired the company, but we still work as two separate companies. We have a small unit in China localising the product" - president

When three MNCs from Europe decide to set up R&D facilities in China, the main decision factor is to better access to the Chinese market, by meeting local customers' need. LifeStyle and Mechanic already have a big presence in China. They choose to locate in Shanghai, where they can get support from the business offices already in operation. BodyGuard's sale in China does not have much share in its last financial year, but it realises that China is a very import market for them and they need to have some R&D presence in China.

On the contrary, two Chinese companies Messengers and Thomas go to the Europe specifically for technology, while ShopSafe has a very clear motive of directly introduce acquired product to the Chinese market. All three overseas units are acquired, hence there is not much decision space for choosing a specific location. The length of acquisition usually lasts less than one year from open to close. The three Chinese companies have to move and decide very quickly when the opportunity window appears. In the case of ShopSafe, the company just went public and had cash for investment. The integration of acquired unit with mother company did not went so well. The president would rather describe the it as a learning process for international acquisition. The company did acquired three more companies outside China since then.

It is also worth noting that all three European companies sent the directors of R&D

from the HQs. The majority of their research or engineering staffs are Chinese nationals. The three Chinese companies did not change the management team and research staffs after acquisition. Messenger and Thomas continue to invest in R&D and both acquired units expend significantly after the acquisition. In terms of integration, Messenger already have a comprehensive R&D network, the acquired R&D centre was immediately given new agenda. Thomas and ShopSafe were kept relatively independent from the mother companies. Both acquired units were given new opportunities to embrace a much big market through mother companies, either through technology transfer or direct product sales.

The three European companies more or less experienced management challenges we have discussed in the previous section. Culture diversity, staff recruiting and retaining, and government relationships are the key challenges for them. Interestingly enough, although China has a weak IP protection regime, LifeStyle and Mechanics both worked out ways to protect their intellectual properties. The three Chinese companies do not seem to have local management issues as the units were given high autonomy in daily operation. The biggest challenge is in creating synergy: how could acquired units fit into mother companies research portfolio and product portfolio?

5. Discussions

The motivations in investing R&D in China or Europe in our case examples is consistent with the literature. There is a clear pattern that European companies invest R&D in China for market purpose, while Chinese companies go to the Europe for better technology. This is a logical choice. However, two of the European companies we interviewed have the ambition to expend their R&D units to full scale research centres: "We see China as a second home" quoted by one interviewee. LifeStyle is now doing research for global market. Mechanics also provide global engineering services. Although there are still concerns about transferring core technology to China, with the growing of China's market and local S&T capabilities, we expect to see more in-depth R&D activities from western MNCs.

Chinese companies tend to use acquisition to minimise risks of operating in an unfamiliar environment. Their target if very clear: complimentary technological resources. With some information asymmetries in acquisitions, it is a trail-and-error process for Chinese companies to embrace the advantages of internationlisation of R&D. With the accumulation of experiences and globalisation of Chinese firms, we would expect to see more and more Chinese companies operating R&D overseas.

This is only a first step of exploratory research. We did find Chinese companies have a different pattern in engaging global R&D activities. It would be beneficial to both research and practice if we can further explore the challenges and corresponding countermeasures by Chinese MNCs.

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Lean Operations Management and its Evolution:
-A Japanese perspective-

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Abstract: Over 20 years has passed already since the concept and methodology of lean management came on the stage of world manufacturing scene.
These years, rapid business globalisation for a background, it is in progress to transfer this approach to offshore factories, to other business functions within the company and furthermore, expected to transfer to other industries such as transportation, medical, civil services etc. Recognizing the situation, this paper, focusing on some extent of generalized operations, introduces the origin of its sense of value, its way of thinking, approach and methodology followed by discussion on the possible direction for its evolution.

Keywords: Loss Zerotisation, Contradiction-driven Approach, Visual Management (VM), Karakuri, Pokayoke, Concurrent Technology, Progress Standardisation, Lean Layout, Heijunka Operations, Just In Time, ICT-assisted management, Constitutionalisation of competitiveness, Horizontal deployment

1. Introduction

These years, business environment of manufacturing industries has been changed drastically. Then, lean management, its original concept and the way, having been popular among professional managers over 20 years seems to be retreating due to mutation of business environment. Actually, it is somehow different from the time that "lean" raises sensation, where market was growing with stability, and many new management problems awaiting to be tackled with. Following issues are some relevant changes of business environment.

1) Globalization and multi-nationalization

Maturity of local market and, therefore, enlargement of free trade with boarder-less investment drive this phenomenon. Linking with this trend, many interesting management topics are revealed as described.

- Mixture of matured, growing, depressing and booming area
- Construction and/or relocation of production sites
- Operations under multi-national and varied environment
- Balancing global and local operations (glocalization)
- Supply chain risk management
- Fluidization and mal-distribution of human resources

2) Diversification of customer needs

This issue emphasizes importance of new product development (NPD) function and provokes the following activities.

- Reinforcement of NPD function by information technology (e. g. CAD/CAM, CAPP, DFX)
- Awareness prioritization of corporate social responsibility (CSR)

3) Digital technology innovation and informatization

Deterioration and less applicability of analog technology are simultaneously going on and, finally, so-called digital revolution occurred in terms of the following manner.

- Functional reinforcement of hardware platform by digital-information technology

4) Commercialisation of information value

Owing to information network development, value and utility of information are widely recognized and following points are very much encouraged.

- Formulation of market ⇨Launch of internet business etc.
- Development of advanced ICT & SNS

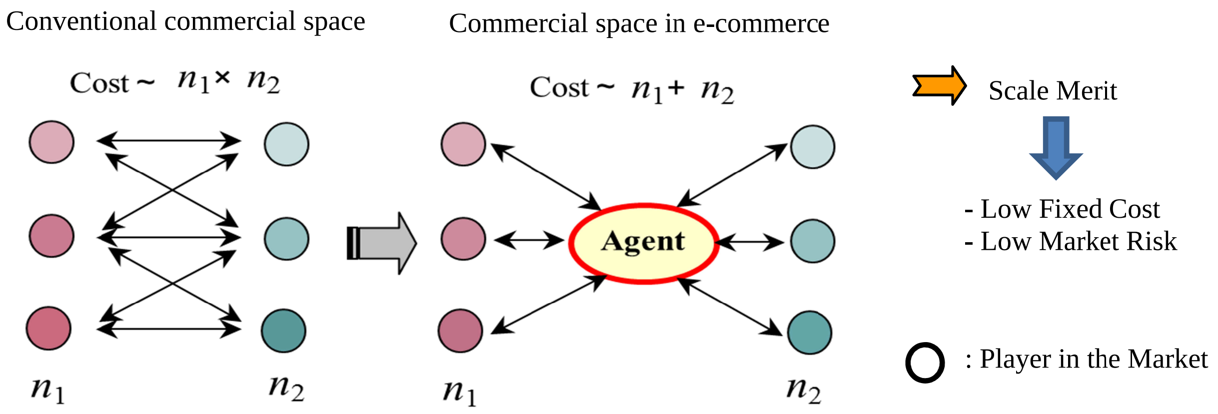


Figure 1. Conventional commerce space vs e-commerce space

Figure 1 illustrates the merit of e-commerce based market, where cost of the market is proportional to the total number of sellers and buyers because matchmaking 2 categories of members are performed through agent system. On the contrary, conventional commercial space needs the cost proportional to the product of 2 categories of members. This means e-commerce market is far efficient to make trade.

5) Shift to information-based management

Based on the above trends, advancement of information technology is also rapidly progressed and implemented to management scene such as ERP systems. This management infrastructure provides following advantages.

-Grasping necessary and/or useful information accurately and timely and utilizing it for management

-Shift from area specified technology to management technology

In this paper, intending adaptation of lean management to business environment changes and focusing on some extent of generalised operations, reconsiders the origin of lean sense of value, its way of thinking, approach and methodology followed by discussion on the possible direction for its evolution.

First of all, let’s re-examine the meaning of “Loss Zerotization”, which is the fundamental sense of value of lean operations management. Everybody agrees “Loss is unacceptable, it should be eliminated!”, however, why are there still a lot of companies struggling with it?, e.g. fire fighting with claims from customers, defects of products, waste in their processes, machine breakdowns and malfunction, minor stoppages, accidents/incidents, inefficiencies of resource utilisation, high turn-over rate, high absenteeism etc.? It is because of vulnerable skills, ineffective methods, weak desire and even tired.

Loss is still exists a lot everywhere in private life, organization (company activities), industrial sectors and also national-wide and global human activities. Following is a list of losses classified in terms of major manufacturing resource-wise.

1) Human (Labour): accident/Incident, absenteesm, turnover, slow-rating, idle, unnecessary work engagement, ineffective work sequence, off-skill etc.
2) Machine (Facility): breakdown, start-up, shutdown, slowdown, minor stoppage, idle, improper job assignment, inflexible capability etc.
3) Material (Transaction): in-flow off-quality (material & parts), in-process off-quality (waste & rework), out-flow off-quality (tangible / intangible complaints & emission), off-timing (inventory)
4) Method (Software, Procedure etc): run-wild progamme, non-concurrent procedures
5) Organization (Venture, Offshore Factories etc.): wrong/ineffective strategy, try & recalibration of venture start-ups, careless offshoring

Zerotization of these losses are very important as it links with KPI categories. For example, “Zero Breakdown / Accident / Waste & Rework etc” is the key for functional durability, “Zero Out-flow Off-Quality” is the key for service competitiveness, “Zero Emission” is the key for environmental sustainability, “Zero Wrong/Ineffective Strategy” is the key for business / social responsibility etc.

2. Way to tackle with the problem

In this section, Japan-grown PDS/PDCA and its extended version are discussed.

Japanese manufacturers have been maintaining their technological strength for some decades up to recent years. Especially Japanese manufacturing operations used to dominate other countries in terms of reliability, efficiency, cost effectiveness etc. and contribute to produce quality goods. Looking at the elements of manufacturing operations, there are various key techniques used for them such as precision die casting in foundry and/or machinery industries. These dies are used for press operation to make car parts for instance, and therefore, car industry can also perform fine manufacturing. These sorts of positive chain reactions are the essential issue of industries’ competitiveness and Japanese manufacturers are taking this factor into consideration in terms of

Keiretsu supply chain management. Besides of such a specific manufacturing techniques, Japanese industries have been devoted also to develop and refine management technologies for manufacturing operation.

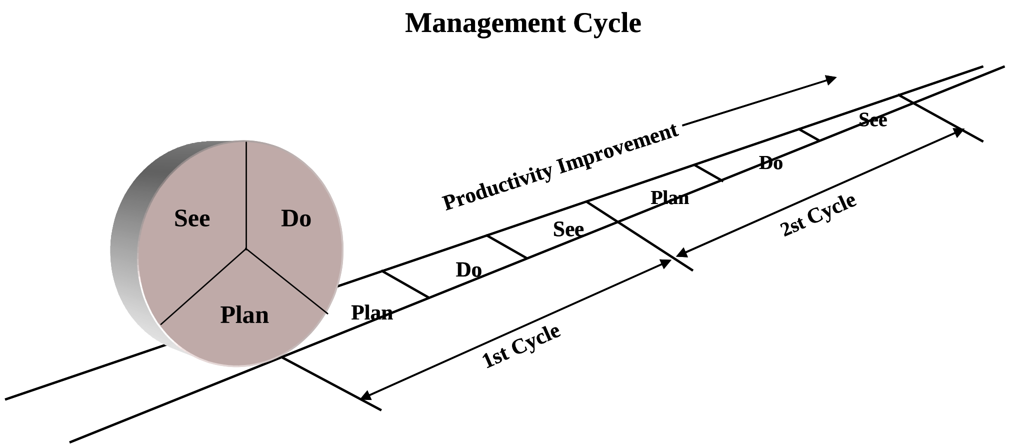


Figure 2. PDS cycle: the original scheme

Particularly, a relevant category of management techniques called Kaizen technology was invented and it has been given huge contribution on manufacturing KPIs. As the essential concept, Plan-Do-See (PDS) behavioural cycle, shown in Figure 2, has been enlightened almost all over the manufacturing industry. This original form is now modified to Plan-Do-Check-Action (PDCA). The idea might be improvement of this schematic cycle itself for better understanding and successful implementation. In fact, “See” is difficult for beginners to understand what to do.

Now, because of globalization, it becomes further difficult to let people, e.g. multi-national employees, to understand what and how to do. Therefore, extension of this original word by deploying detail steps such as Table 1 is unavoidable.

Table 1. Deployment of management cycle

PDS Cycle	PDCA Cycle	Activity Deployment 1	Activity Deployment 2
Plan	Plan	Plan	Forecast
			Generate Plan
		Organise	Organise
Do	Do	Command	Create Motivation
			Transmit Mission
		Execute	Execute
See	Check	Control	Measure
			Evaluate
			Control
	Action (Act)	Adjust	Adjust

3. The concept of lean operations management

In this section, Contribution of lean operations management to industrial and social society is discussed. Figure 3 illustrates the concept of lean management, where manufacturing systems provide conversion process from input to output, and essential concept of lean is to realize fewer resources with higher level of outcomes. Namely, it tries to attain ultimate efficiency and/or effectiveness.

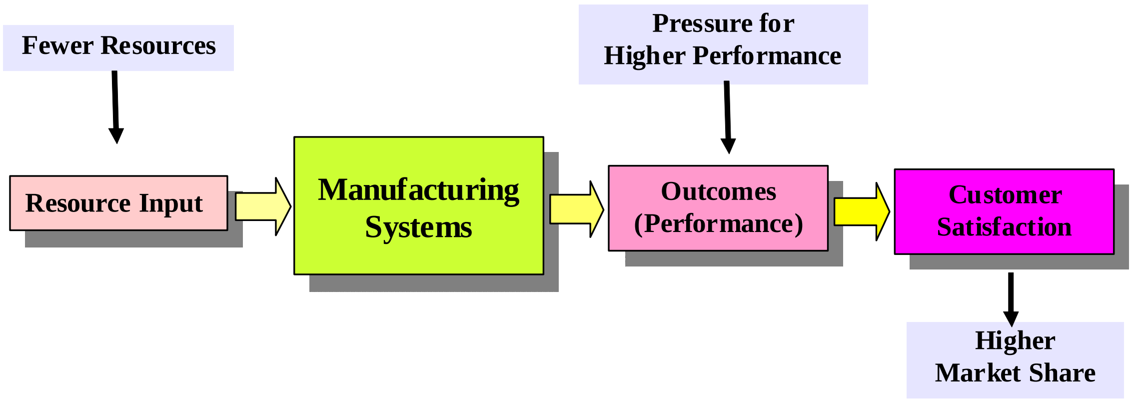


Figure 3. Concept of lean management (Katayama, H. and Bennett, D. J., 1996)

This means manufacturing systems must be trained hard for better outcomes with fewer inputs. Figure 4 illustrates relation between resources and outcomes, where resources consist of human, machine, material, method money etc. that must be converted to skilled human, advanced machine, advanced material, improved method and reward respectively.

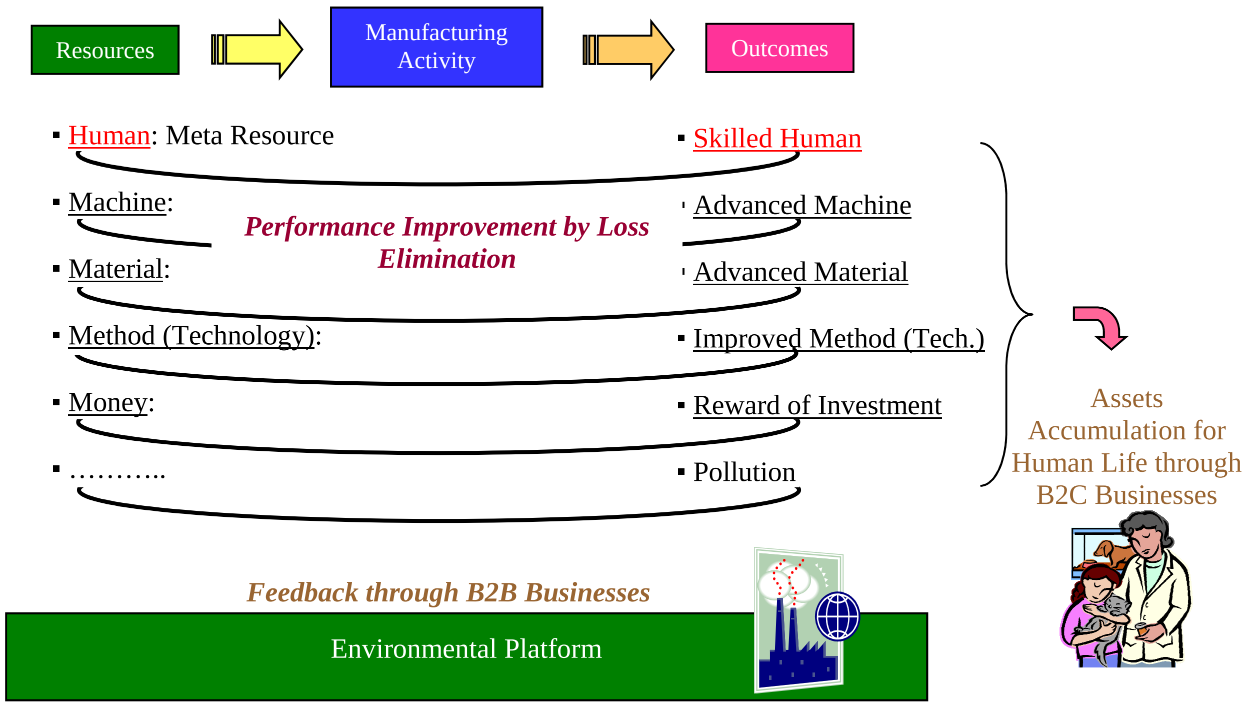


Figure 4. Relationship among resources and outcomes from manufacturing operations

For example, human resource (HR) is the most important resource among corporate resources as it enables to control other resources as the meta resource. It is not only the driving force for formulating best corporate quality, but also it elevates its ability through operations. In a lean organization, this sort of positive spiral must be constitutionalized.

Philosophical stance to lead organization toward lean can be called “Contradiction-driven Approach”. This means that, firstly, the leader delivers mission impossible and/or difficult to the followers, then, they are asked to think and act on the platform of PDCA cycle to reach the object as close as possible. Two examples of this way is described as follows.

Figure 5. Stance of lean operations management

Example in TPS (Toyota Production System, which is a representative lean scheme)

1: KANBAN System for visualizing bottleneck operations

One important parameter of “KANBAN System” is the number of KANBAN, which is used for visualising weak operative functions by suppressing number of KANBAN one by one. Then, improvement activity is applied to overcome the weakness.

2: Leader’s mission delivered for NPD division

“Let’s develop a car which enables to purify air during it run.”

Example in TPM (Total Productive Maintenance & Management, which is another representative lean scheme)

1: Zero break down by PM (Phenomena-Mechanisms) Analysis

This technical method is to investigate the causal relation between phenomena and mechanisms thoroughly by using knowledge of physics, chemistry, mechatronics, statistics etc.

2: Zero fluctuation by 4M Analysis and standardization

This method is to investigate the resource-wise conditions and settle the parameter values to guarantee quality and stable output.

By this stance, lean organization creates many successful experiences and also realizes strong organisational constitution. Key point for further empowerment of lean constitution might be procedure establishment for creating leader’s mission, way of delivery, method to solving etc.

4. The feature of lean operations management

In this section, the feature of sales, production, supply and R&D divisions in lean enterprises is summarized for better understanding (Womack, J. P., Jones, D.T. and Roos, D., 1990).

1) Feature of sales division of lean company

Distinctive points are summarized below. Mutual trust between customers and concerned divisions are established by these structures/activities, which enables aggressive sales activity.

-Dealer network system reinforced by mutual shareholding between dealer and manufacturer

-Capturing customers' information and its follow-up

-Reduction of product inventory (linking with second issue)

-Training sales people by job rotation, team working and communication with other divisions

2) Feature of manufacturing division of lean company

Distinctive points are summarized below. By these activities, human errors are reduced and then, work-in-progress, workers for trouble shooting and floor spaces can be all reduced. Finally, fire fights can be eliminated.

-Training at shop-floor, which enable to transfer duty and responsibility to shop-floor workers

-Thorough investigation of defect causes

3) Feature of R&D division of lean company

Distinctive points are summarized below. By these activities, human errors are reduced and then, work-in-progress, workers for trouble shooting and floor spaces can be all reduced. Finally, fire fights can be eliminated.

-Leader scheme, who covers entire process from design to sales

-Team working by professionals in various area

-Proactive communication and negotiation from the beginning that contributes man-hour reduction

-Implementing concurrent engineering in R&D division

4) Feature of procurement division of lean company

Distinctive points are summarized below. By this contrivance, reliance on procurement and supply logistics operations is encouraged.

-Collaboration with material and parts suppliers, which enables focused ordering

5. Lean schemes and their approaches

In this section, focussing on some typical lean schemes, such as TPS (Toyota Production System) and TPM (Total Productive Maintenance & Management), the way of thinking, approach and structure are discussed.

There are several lean schemes developed in Japan and some of them are listed below.

1) Total Quality Management (TQM)

2) Total Productive Maintenance and Management (TPM)

3) Total Productivity Management (TP Management)

4) Hoshin Kanri (Policy Deployment Process)

5) Many company-developed in-house performance improvement schemes such as Toyota System

Each scheme has its own feature and, within these, structure of TPM scheme is introduced here as it is well structured and provides wide range of applicability. The feature consists of following 5 issues.

a) Drivers that are organised in terms of nine major pillar teams

b) Loss analysis as constitutional logic

c) Improvement tools as technological actuator

d) Seven levels of programme

e) Stepwise approach

It is also valuable to examine a fusion of these schemes to reinforce lean weapon. Here, a combined procedure of TPM and TP Management is presented for example, which can be called “framework of strategic TPM”. It consists of Kaizen target setting, its decomposition, solving tiny many loss reduction problems, aggregating outcomes and gap analysis.

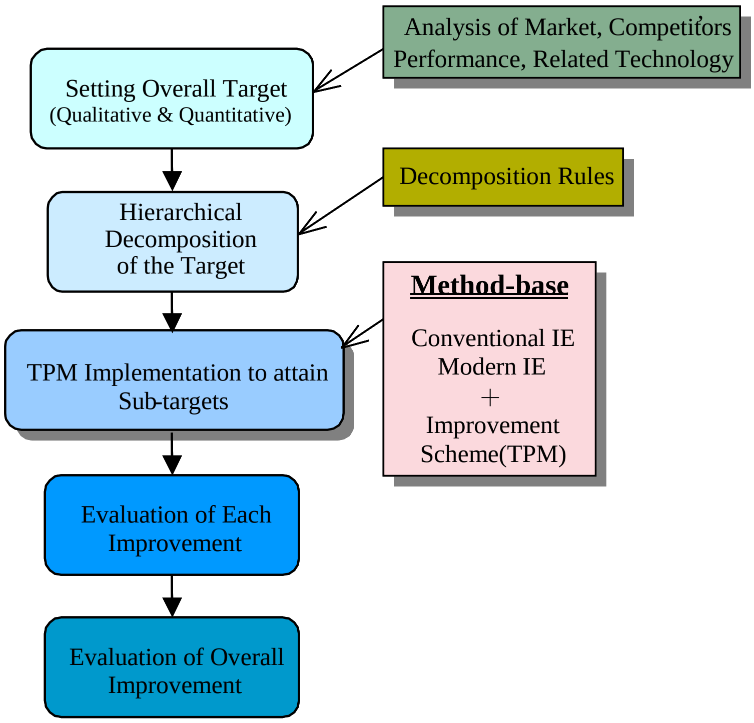


Figure 6. Strategic performance improvement procedure [6]

More detail procedure is given in Figure 7, where 15 detail steps are included. The aim of this flowchart is to provide stepwise procedure (feature of TPM) to examine company’s strategic direction, its formulation, numerical target setting (feature of TP Management), decomposed target assignment (feature of TP Management) to pillar teams, launching Kaizen activities by referring improvement method-base, accumulating result of each project through time-based control of project progress, Comparison/gap analysis between target performance and obtained outcomes. This sort of detail procedural approach is the essence of TPM scheme and even strategic matters can be approached by such a way.

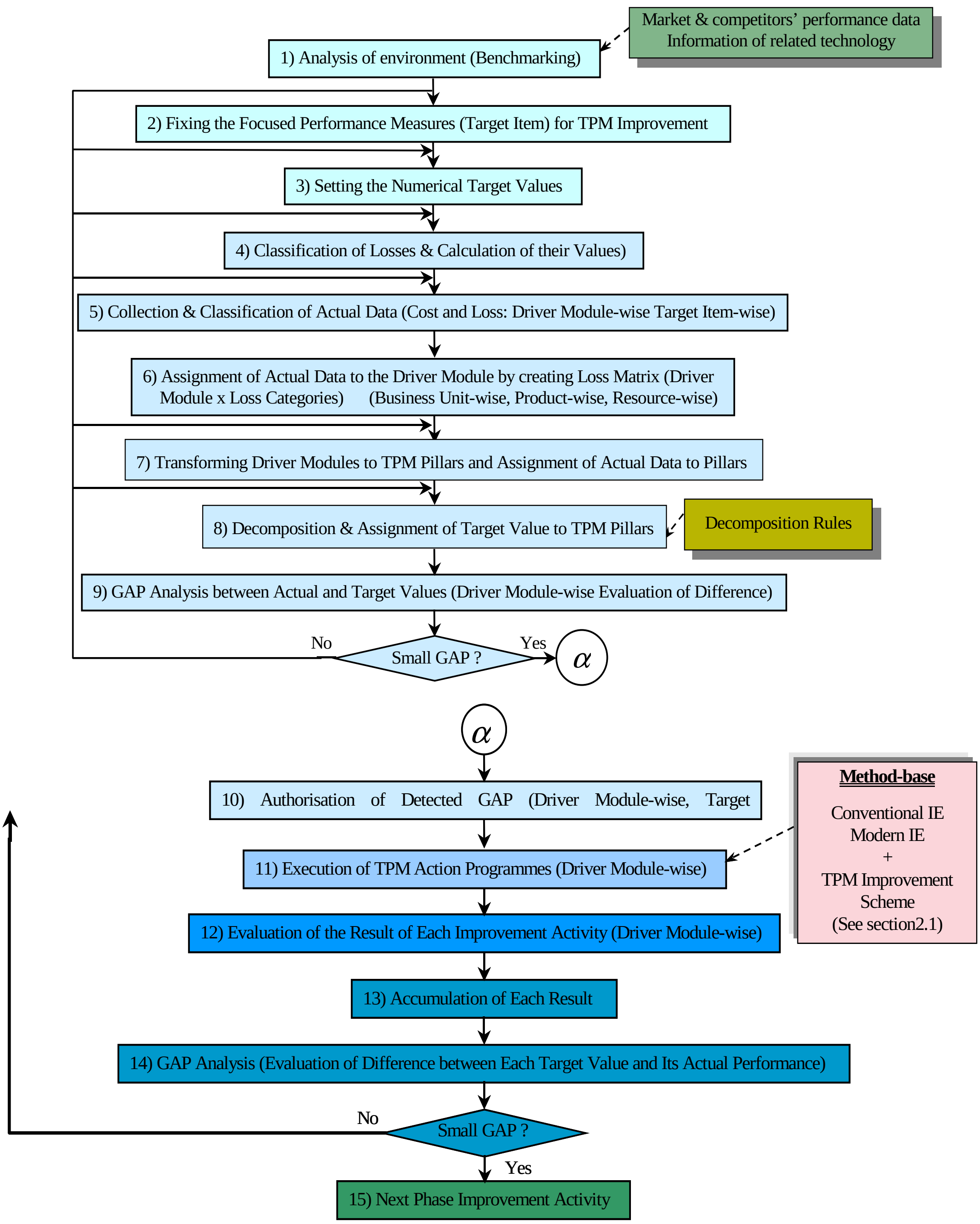


Figure 7. A strategic performance improvement procedure（Detail）

6. Elemental technologies of lean scheme

In this section, typical methodologies, such as "Loss Analysis" as constitutional logic of lean, distinctive lean technologies/methods including Visual Management (VM), Karakuri, Polayoke, Concurrent Technology, Progress Standardization, Lean Layout, Heijunka, Just In Time, are referred.

1) Loss analysis

This is an unique element of TPM scheme enabling to realise performance improvement as loss is the root cause of low performance. In this principle, the entire sequence of definition of loss categories, their quantitative measurement and designing the way of their elimination has to be performed appropriately. Table 2 summarized general categorization of losses with definition, which consists of facility-oriented losses and management activity-based losses that is upper level of classification.

Table 2. Losses and their definition (Continued…)

Loss class	Loss category	Definition
Traditional Facility-oriented Losses	Equipment failure (Breakdowns) loss	Time lost during sudden production stops occurring when equipment loses its specified functions
	Scheduled shutdown loss	Time lost during production stops due to planned annual shutdown maintenance or periodic maintenance
	Start-up & shutdown (Change time) loss	Time lost during the end and the next start of production run associated with stopping equipment and preparing the equipment for start-up
	Speed loss	Loss due to running equipment at actual speed lower than optimum production speed
	Quality defect loss	Losses due to production of defectives and physical losses from scrap, losses from product downgrading
	Minor stop loss	Unscheduled machine stops that can be repaired by production associate
	Rework/Reprocessing loss	Recycling losses due to sending defectives through a previous process
	Others	-------------

Table 2. Losses and their definition

Loss class	Loss category	Definition
Management Activity-based Losses	Planning loss	Unscheduled machine stops due to not having the right material or information at the right place at the right time
	Training loss	Labour loss due to associates with less appropriate skills
	Over/Under manning loss	Losses that result from improper labour assignments
	Inspection & testing loss	Non-value added manpower related to inspecting & testing
	Waste loss	The difference between input volume of material and output volume of good quality product
	Obsolescence loss	Write downs due to closeouts, obsolete etc.
	Energy loss	Energy that continues even though machine is not producing
	Discounts loss	Quality discounts, remnants and returns & allowances
	Return & allowances loss	Financial losses due to returned from customers
	Others	-------------

New loss categories must be considered in regard to supply chain activity as this operation is quite complicated as it is collaborative operation among concerned firms. Various losses concern to sacrifice performance and most of them are not actualised. To tackle with these losses, root cause investigation and correlation analysis among losses are critical. Another possible extension will be establishment of ″Sales Opportunity Loss”.

2) Technologies/Methods

There are many unique technologies and methods, some of them are world well known issues as introduced in the related books (Womack, J. P., et al., 1990), (Monden, Y., 1993).

a) Operation Smoothing Techniques (Heijunka): Dispatching method for stable parts consumption and/or man-hour consumption (Example: Target Chasing Method- TCM) etc.

b) Inventory Reduction Systems: Demand-pull logistics (KANBAN System) etc.

c) Lead-time Reduction Methods: Concurrent operation & small lot operation Shingo`s Single Minute Exchange of Die (SMED), One Piece Flow etc.

d) Lean Layouts: Function-wise vs Multi-functional Layout, U-shape etc.

e) Operation Standardization: Visualization of Working Pace etc.

f) Autonomous Mechanisms: Automatization & Poka-Yoke (Fool-Proof)

g) Other general improvement tools: Table 3.

Table 3. Members of TPM improvement toolbox

Tool	Contents
5S	Five important issues for factory, i.e. Seiri(Rationalising), Seiton(Arranging), Seisou(Sweeping), Seiketsu(Cleaning), Shitsuke(Training)
5 Why Analysis	A search method of failure/defect cause
VC/VM	Visual Control/Management
Poka-Yoke	Error-safe (*Fail-Safe*), Error-free mechanisms (*Poka-Yoke=Fool-Proof*)
Karakuri	Sophisticated Technological Contrivance developed by Mechatronics etc.
PM Analysis	A method to analyse the relation between failure phenomenon and resources
4M Analysis	A method to establish the right condition of resources for right production
Process Point Analysis	A method of process failure elimination by focusing on the points that material is processed
FTA	Fault tree analysis, an elemental technology of preventive maintenance, which investigates root causes of fault mode.
FMEA	Failure mode and effects analysis, an elemental technology of preventive maintenance, which investigates statistical relation among failure modes and their effect on other systems to reduce the occurrence of actual failures
Mapping	Benchmarking & horizontal deployment
IE Technologies	Motion-time study, work measurement, control chart, statistical tests etc.
Others	Simulator, retrieval engines, project management software, skill management tools, CAE, QC 7 tools (Check sheets, Pareto graph, Histogram, Fishbone diagram, Control chart, Dispersion graph, General graph), New QC 7 Tools, DOE, PCI, **Toyota Production Systen** etc.

Besides of these conventional tools, new IT infrastructure and tools can be useful for quick and/or large scale analysis. Following software systems are hopeful tools for described subjects, which might contribute improvement of lean scheme itself.

① Method-base of successful improvement for horizontal deployment (Improvement Dictionary)

② CAE software for examine the way of improvement

③ Product design software for evaluation of product quality, manufacturing cost, operations lead-time etc. (DR/CR tool)

④ Project management software packages such as PERT, WBS for new product development, initial phase equipment management etc.

⑤ R & D management software tools such as TRIZ

⑥ Skill database and carrier path management software

⑦ Company performance measurement software such as activity based costing system, Balanced Scorecard (Factory models enabling OEE evaluation etc.)

⑧ Financial management system such as EVA simulator, free cash flow reporting system

⑨ Risk evaluation system, Environmental system dynamics

7. ICT-assisted lean operations management

In this section, an extended procedure of lean operations management with big data is discussed. It consists of following 5 steps.

1) Classification of performance data
2) Dara collection and database construction for performance benchmarking, road-mapping and competitiveness analysis
3) Causal relation analysis among performance data
4) Constitutionalization of competitiveness by PDCA Cycle
5) Horizontal deployment of best practice

A topic to discuss here is “Reinforcement of Performance Evaluation and Improvement System”.

1) Classification of performance data

In general, performance data is often called KPI, however, noticing that there is structural relationship among KPIs, it might be appropriate to classify in terms of some layers described below (Example).

a) KSC: Key Social Contributors, which relate to CSR issue.
b) KMI: Key Management Indicators, which directly relate to corporate management, and therefore, has monetary dimension.
c) KPI: Key Performance Indicators, which relate to operational outcome and has physical dimension.
d) KAI: Key Activity Indicators, which relate to operational input and has physical/monetary dimension.

2) Data collection and database creation for benchmarking, road mapping and competitiveness analysis

Once each performance indicators defined above is quantified, database of each category must be created of which visualized data can reveal company’s position in the market, strength and weakness in comparison with competitors and enable to draw a hopeful way for growth in terms of road mapping. To realize these performance visualization, analysis and planning, information infrastructure such as Enterprise Resource Planning (ERP) system combined with Manufacturing

Execution System (MES) might be necessary.

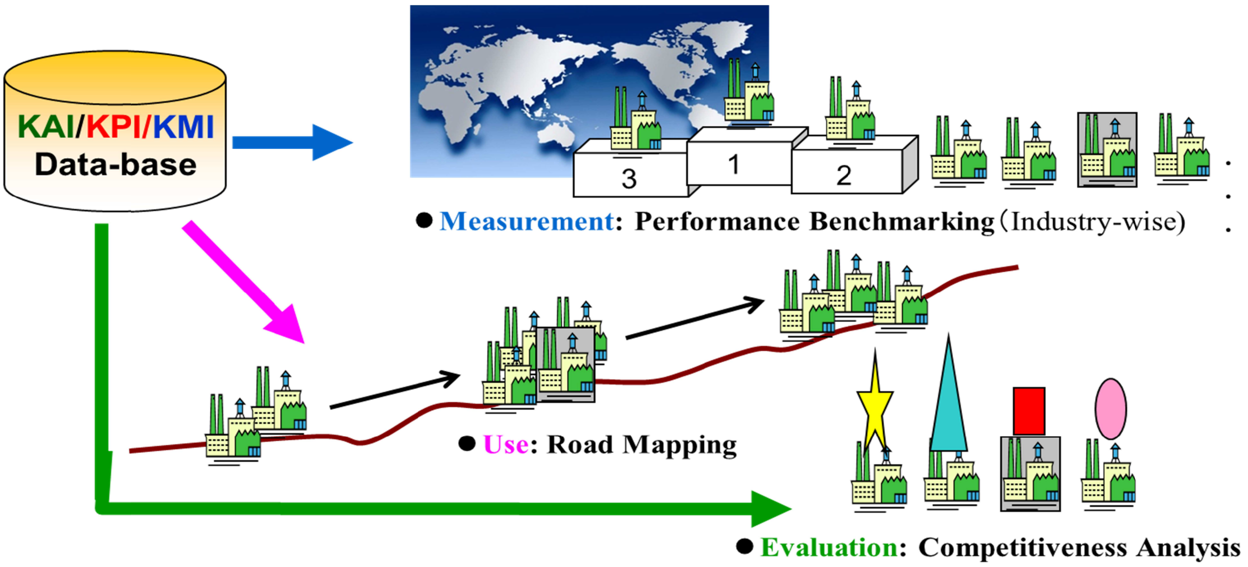
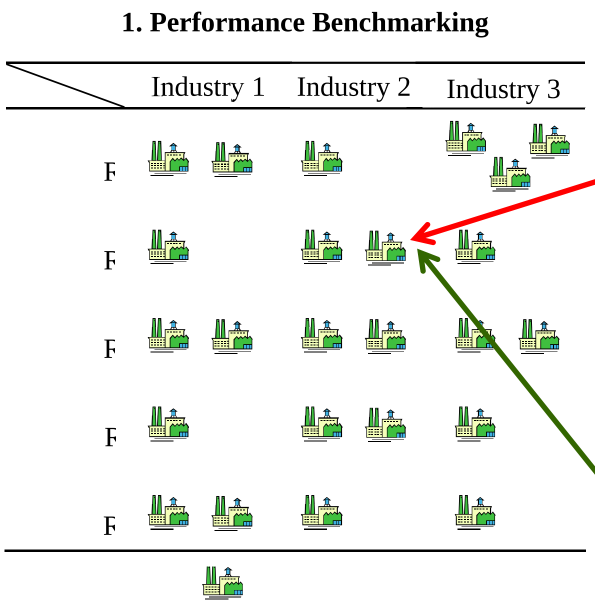


Figure 8. Framework of KAI/KPI/KMI Data-base

3) Causal Analysis among Categories of Performance Data

Then, relation between performance data is possible to obtain by utilizing some statistical causal relation analysis as shown in Figure 9.



KPI Data (Term-wise Trend)

	KPI 1	KPI 2	⋯	KPI r	⋯	KPI s
BU 1	Data (b_{11})	Data (b_{12})	⋯	Data (b_{1r})	⋯	Data (b_{1s})
BU 2	Data (b_{21})	Data (b_{22})	⋯	Data (b_{2r})	⋯	Data (b_{2s})
⋅ ⋅ ⋅	⋯	⋯	⋯	⋯	⋯	⋯
BU k	Data (b_{k1})	Data (b_{k2})	⋯	Data (b_{kr})	⋯	Data (b_{ks})
⋅ ⋅ ⋅	⋯	⋯	⋯	⋯	⋯	⋯
BU n	Data (b_{n1})	Data (b_{n2})	⋯	Data (b_{nr})	⋯	Data (b_{ns})

KAI Data (Term-wise Trend)

	KAI 1	KAI 2	⋯	KAI i	⋯	KAI m
BU 1	Data (a_{11})	Data (a_{12})	⋯	Data (a_{1i})	⋯	Data (a_{1m})
BU 2	Data (a_{21})	Data (a_{22})	⋯	Data (a_{2i})	⋯	Data (a_{2m})
⋅ ⋅ ⋅	⋯	⋯	⋯	⋯	⋯	⋯
BU k	Data (a_{k1})	Data (a_{k2})	⋯	Data (a_{ki})	⋯	Data (a_{km})
⋅ ⋅ ⋅	⋯	⋯	⋯	⋯	⋯	⋯
BU n	Data (a_{n1})	Data (a_{n2})	⋯	Data (a_{ni})	⋯	Data (a_{nm})

Figure 9. Structure of KAI/KPI Data-base

4) Constitutionalization of Excellence through PDCA

Getting the valuable result in the previous steps, all of the activity can be iterated on the platform of PDCA cycle as shown in Figure 10. Where, in the “Do” phase, improvement activities are took place and successful as well as unsuccessful experiences are accumulated in terms of cases, by which revised improvement case-base is fulfilled. On the other hand, in the “Check” phase, resultant performance data obtained through improvement activities are classified and put these into performance database. Then, these are utilized for “Action” phase as well as next “Plan” phase. This process must be performed as an infinite loop of bench marking and improvement. Also, this structure can be utilized for reinforcement of joint ownership of corporate sense of value. Further, this can be extended to cover entire supply chain.

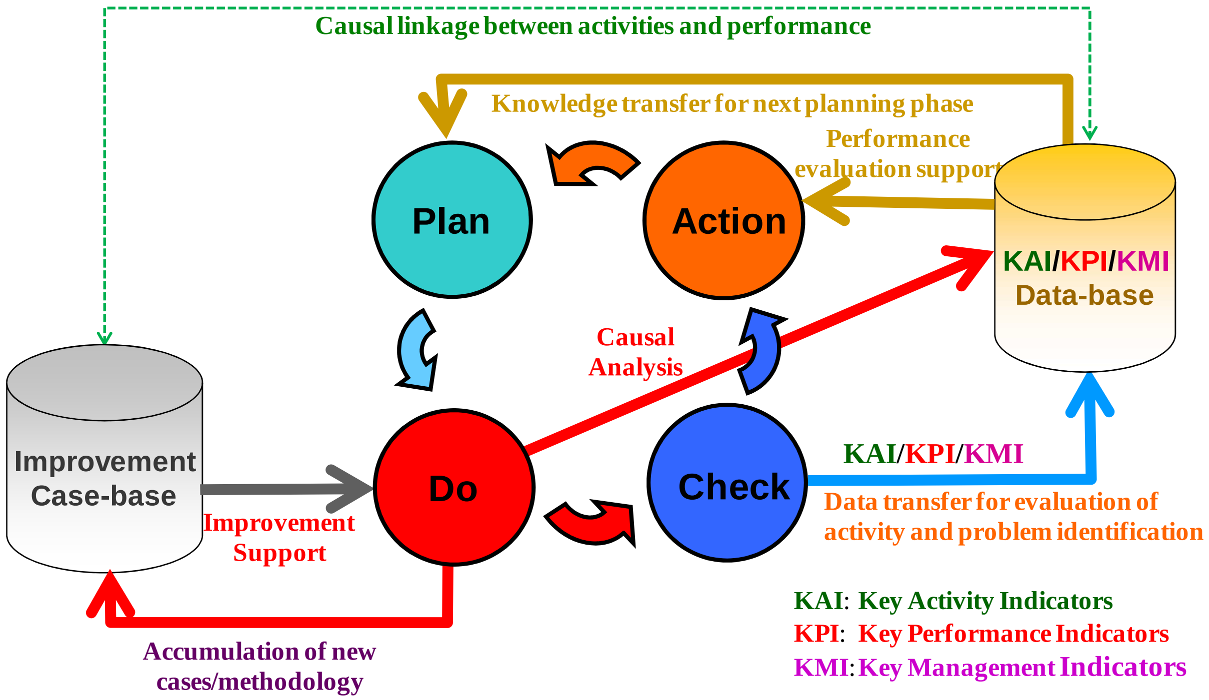


Figure 10. Relationship between Activity and KPI on the PDCA Scheme (Example)

8. Deployment of lean operations management

Finally in this section, development and implementation of effective transfer methods (vehicles) in-between sites, business functions, business divisions and industries are discussed. Where, vehicle is performance improvement technologies (example), supposed activity is mutual learning (example) and system considered is ERP (example).

It is also necessary to involve latest ICT assets in lean activity as it activates based on deep appropriate knowledge on the data. Software products have a lot of layers from that managing higher level of KPIs such as EVA evaluator to that capturing shop-floor activity-based data. Here, the latter type of information infrastructure seems to be quite supportive if it is appropriately implemented. Because it becomes realistic all of the necessary KPI values can be reported frequently through utilizing automatically captured shop-floor data. Linking these data with strategic performance improvement procedure, ICT assisted strategic TPM for example can be recognized, whose outline is illustrated in Figure 11.

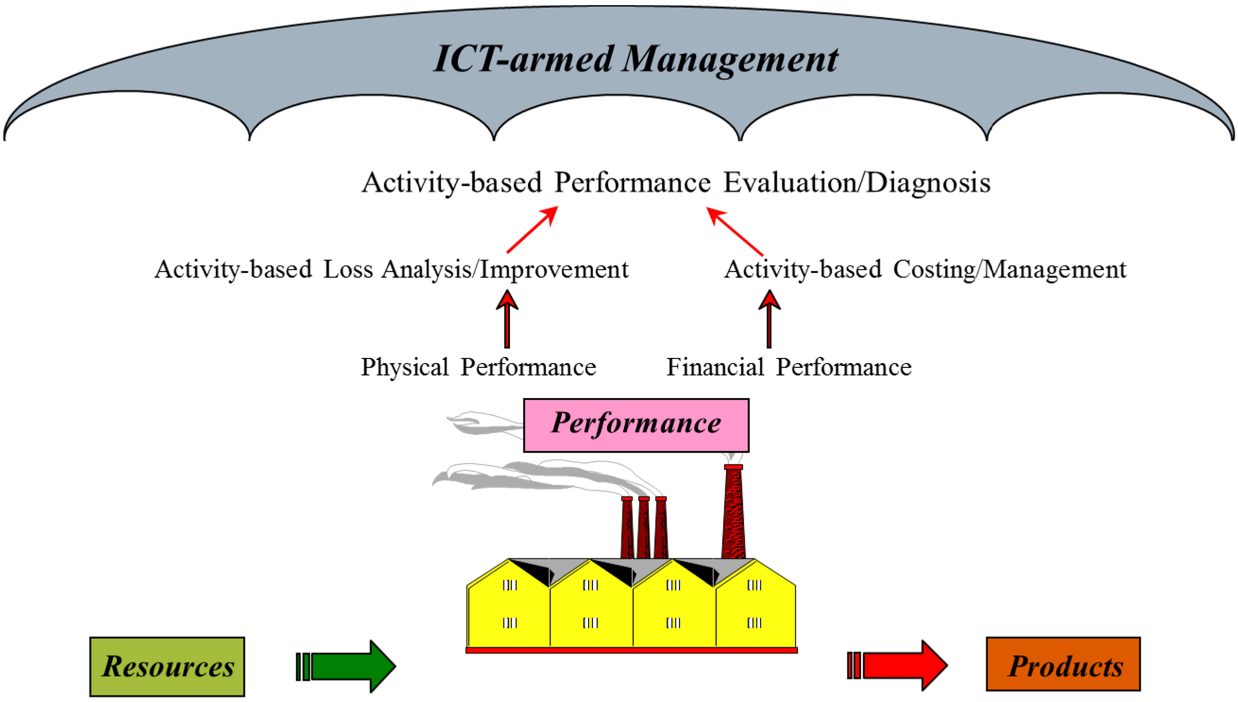


Fig. 11. Structure of ICT-armed Management (e.g. ERP-assisted)

As the final note, horizontal deployment of the contents discussed in this paper is discussed. Pattern of lean operations management transfer is categorized into 3 portions mentioned as follows.

There are three types of transfer *i.e.* special, functional and inter-industry transfer. The first is to transfer to different sites such as offshore factories from domestic factory and transfer among offshore factories. The second is to transfer to other business functions such as lean management transfer from factory to sales division.

The last is to transfer to other industries from manufacturing to service industries such as hospital, logistics industries etc. As shown in Table 12, 13 and 14, its global transfer already occurs and is getting popular. Major enablers contributing this phenomenon will be highly depending on the feature of lean scheme. Functional transfer is also popularized among divisions as new driver establishment strongly encourages its transferability.

① Various patterns of spatial transfer

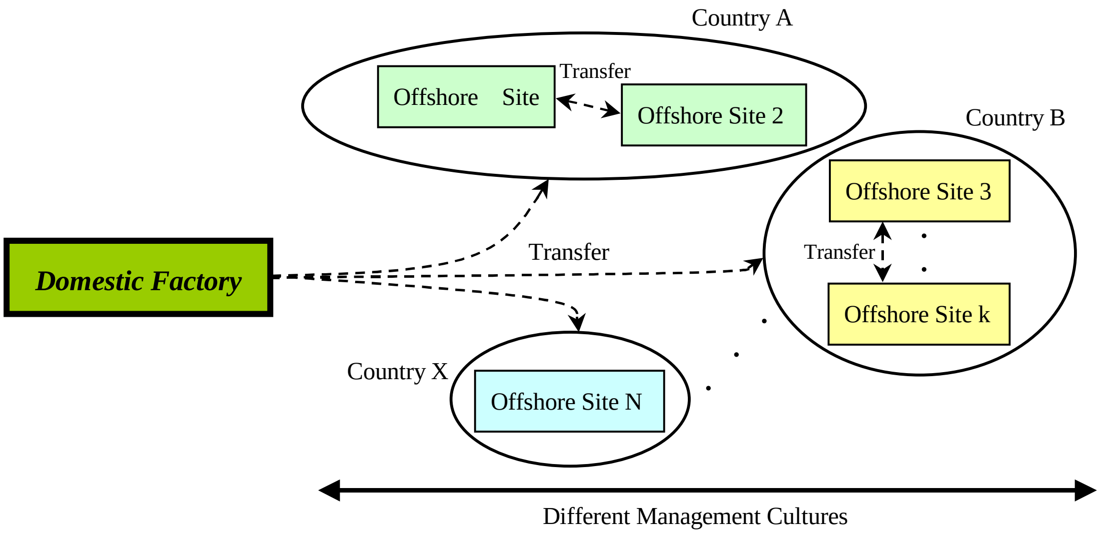


Figure 12. Lean management transfer from domestic site to offshore sites

② Various patterns of functional transfer

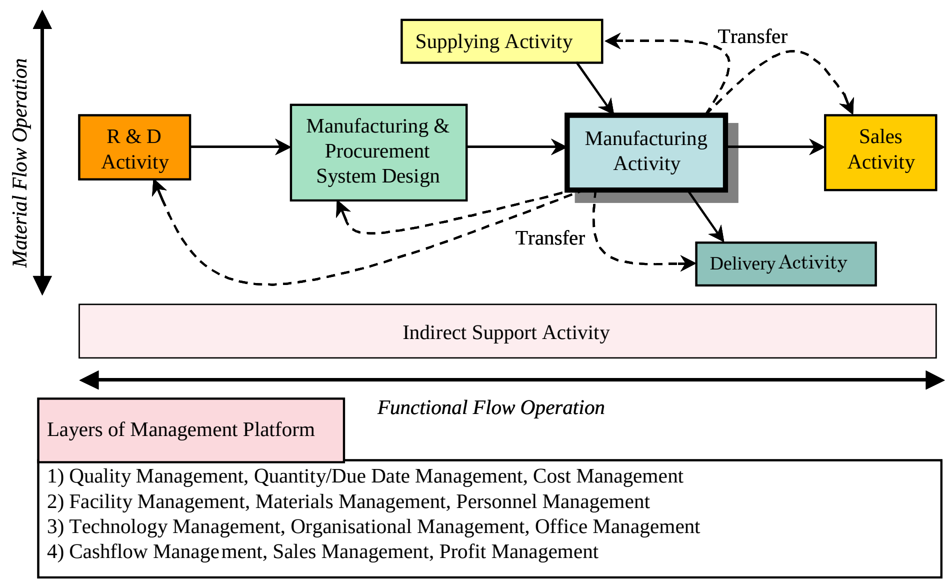


Figure 13. TPM Technology Transfer to Other Business Functions [8]

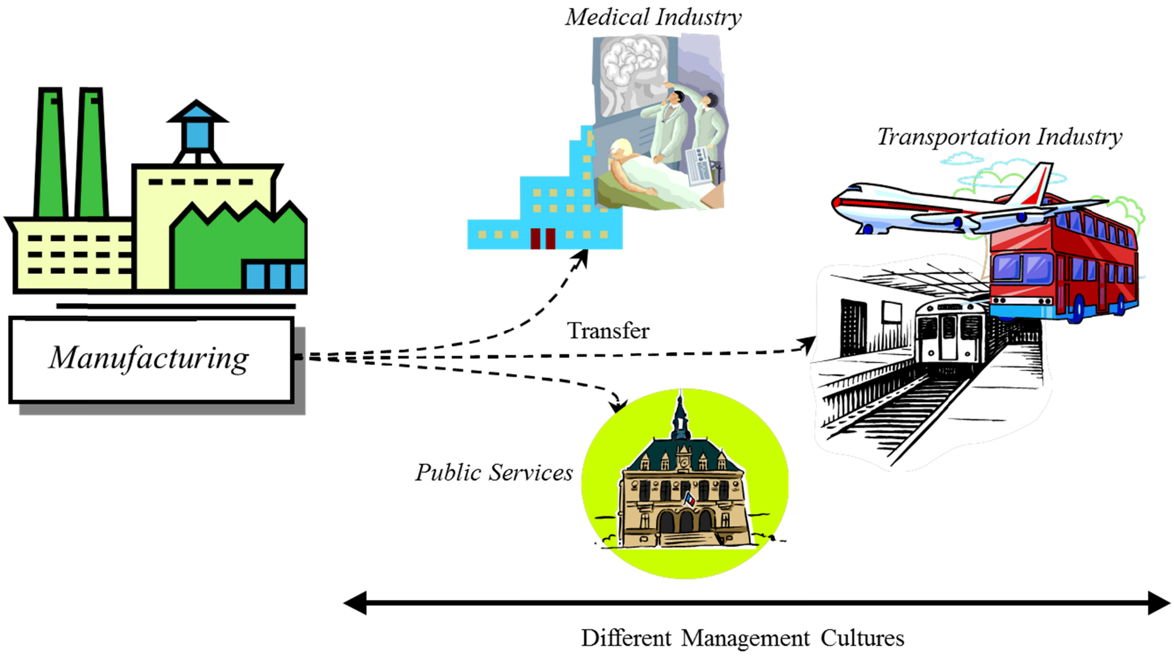


Figure 14. Inter-Industry Transfer

9. Concluding Remarks

This paper, focusing on generalized manufacturing operations, introduces the origin of lean sense of value, its way of thinking, approach and methodology followed by discussion on the possible direction for its evolution. Topics provided for discussion were all about on-going or future issues, therefore, concrete message is tough to deliver. However, these are still valuable to examine as the thought provoking matters.

Acknowledgement

This paper contains some figures which were drawn by Associate Professor Koichi Murata at Nihon University during his doctor dissertation supervised by myself. The author sincerely appreciates his support and efforts on the fine figures used.

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Critical Factors in Designing of Lean and Green Equipment

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Abstract
Designing production equipment considering lean and related sustainability requirements may be a major factor in achieving productiveness through lean implementation. The objective of the study is to investigate the impact of lean production requirements on equipment design and how the lean requirements affects early design phases and global footprint. Data collection method includes literature review and in depth interviews with equipment users. The results provide support to importance of considering green and lean requirements in designing of production equipment by introducing important lean design factors for production equipment. These factors are designing simple equipment, error-proofing, being portable and flexible, supporting one piece flow, supporting short setup time, easy and reliable maintenance, supporting the operator interface with machine, safety of the operator, supporting production processes and layouts, energy efficiency, easy to operate, minimum cost, visualization, straight flows, teamwork, standardization, quality assurance, using pervious experiences, easy to clean, and easy to control.

Keywords: Equipment design, lean equipment, green, sustainable equipment

1. Introduction

Lean thinking with its principles and methods has had a considerable role in developing effective and practicable processes in the competitive market (Bicheno et al., 2011; Liker, 2004; Modig and Åhlström, 2012). It is important to design production equipment and infrastructure in accordance with the demands of the lean production system (Herrmann et al., 2008) and may be a critical factor in facilitating lean implementation in production.

Lean production, stemming from the Toyota production system has no static definition, rather it is evolving continuously (Hines, 2009). Recent development is also more and more including sustainable development as companies are challenged with improving environmental performance and social responsibilities (Pampanelli et al., 2013). Eco-design of equipment that use energy and other consumables should usually focus on the use phase (Jönbrink et al., 2011)

For equipment used in manufacturing, especially green lean principles/requirements addressing material, energy and waste efficiency may be of importance (Smith and Ball, 2012).

This paper aims to investigate if identified lean or green principles are used and how they are reformulated when purchasing equipment in industrial companies in Sweden.

2. Theoretical background

2.1 Lean manufacturing principles

Lean production means a production system which is continuously improving and avoiding losses. This is a system that are often described by a set of principles as base for the lean management (Liker, 2003). Depending on operation and business the set of principles differs, but still are variations of similar sets of principles (Netland, 2012). The principles are connected to the company values and can be seen as guidelines or a rule base for the production system (Kurdve et al., 2014). These rules then are used to specify methods, tools and standards that direct operations and improve the system as shown in figure 1.

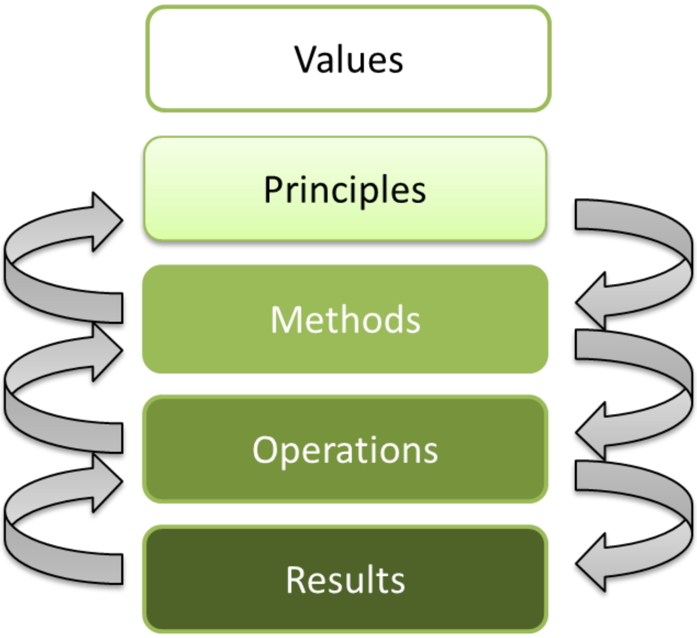

Figure 1: Principles are used to guide the operations of the production system

Lean production includes methods and tools to improve the system, minimize resource use and increase the value in each step of a process. Liker (2003) mentions seven different waste factors that all should be eliminated:

1. Overproduction – do not produce more than necessary
2. Waiting (time on hand) – reduce waiting time in the process
3. Unnecessary transport or conveyance – reduce transport time
4. Over processing or incorrect processing – do not process anything more than necessary
5. Excess inventory – keep the material rates down
6. Unnecessary movement – have all equipment where it will be used
7. Defects – keep a low rate of defects

Lean may be defined as consisting of two separate parts, one strategic or management level and one operational level with tools and methods. Some of the tools used within Lean are 5S, Value

Stream Mapping, Kaizen and Kanban (Song et al., 2009). Lean tools can be implemented in almost every operation as long as you interpret the tools in a way suitable for the purpose that you are going to use them in (Hines et al., 2004). While the operational level may be bound to lean manufacturing, the strategic part can be used also in other areas since it only applies the mentality or mind-set of lean thinking.

Lean thinking is connected to use of principles as general strategic guidelines. Although different authors and different companies mention somewhat different lean principles, they are mainly variations of similar sets (Netland, 2013). Liker (2003) mentions fourteen Toyota Way Principles, of these seven are process focused. The process focused principles are those that anticipated to be most important in production equipment design.

The first principle is creating flow. The goal is to create an even and stable flow, by trying to avoid queues in the production and reducing as many bottlenecks as possible. The second principle is pull. The main thought behind this is to only produce products when there is a demand for them. By doing this, you can reduce the risk of overproduction, at the same time that you can adopt the production speed after the market demands. The third principle is to level out the workload of all processes and eliminate the extra work on people and equipment. The forth principle is to get quality at first time. In order to achieve this objective, it is needed to stop the whole line for fixing the problem. Hence, it is essential to have error proofing production equipment which can have a visual alert system to notify the operators or project leaders from the problems (Jidoka is the term for machine with human intelligence).The fifth principle is to create standardization in the processes. Therefore the best practices in each processes is needed to be captured and used as a standard for future attempts. Using simple visual control in order to facilitating the findings of problems is the sixth principle. Utilizing only reliable and tested technology which "supports the people not replace them" is the seventh principle.

It is notable that top management support and involvement, the adoption of a learning-by-doing approach and actively sending feedback are the main facilitators in making these principles more effective. Based on Liker (2003), these factors are categorized as strategic principles. These strategic principles include (1) decision based on long term financial goals, (2) train leaders from people inside the company to support and involve actively within the organization, (3) develop exceptional teams and personnel, (4) respect and help the suppliers to grow and develop, (5) solving the problems by checking and observing the source, (6) evaluate all options in making the decisions and then implementing rapidly and (7) continuous improvements and actively sending feedback.

Recent development of lean production has brought it closer to sustainable development and resource efficiency (Zokaei et al., 2013). In order to include environmental concerns, eco-design can be used to optimise the functionality and lifespan, lower environmental impact from the use-phase (especially minimise energy use), lower the amount of material used, choose the right material, optimise life, distribution and recyclability of a product (Jönbrink et al., 2011). When applying eco-design on production equipment, the use phase is the most significant phase to improve and equipment should be designed to be long life, functionally optimised, energy efficient and use low amounts of process material and maintenance. For equipment connected to process fluid systems, earlier studies (Kurdve and Dagini, 2012) has shown that three main design principles for the process fluid system are:

- The equipment should be easy to clean
- The equipment should be easy to maintain and repair

- The process should be easy to monitor, control and maintain.

2.2 Main factors in purchasing and designing equipment

Some important factors for equipment purchasing are that the equipment should support high quality production, optimal size of equipment for the expected product volumes, low complexity of the equipment, quick change-over time, low equipment maintenance cost, short product lead-time, low inventory level of product, flexible equipment for future product design and volume changes and design that facilitates involvement of engineers and operators (Edwards 2006, Jamie 2005). “Being able to keep maintenance tasks away from the operating Work”, also called the ‘line-back principle’ should also be considered (Jamie 2005). In addition ‘error proofing’ is critical (Jaamie 2005, Hought 2012) and four main types of human failures mentioned by Hought (2012) are slips, lapses, mistakes and violations. The most dangerous types of human failures is “mistake” and thus he pinpointed safety and simplicity as a critical factor in designing lean machines.

A previous study at Rockwell Automation (2004) mentioned that companies need to evaluate the balance between risk of over-engineering or under-engineering. Some factors which guide assessing of risks in lean control system design are: matching the equipment with the requirements, availability and stability of technology, realistic design solutions, eliminating waste, short term and long term cost, flexibility of equipment.

Small construction projects has shown differences between lean and green requirements with regards to project size, locations, etc. (Koranda et al 2anufacturing on 011). However the similarity of demands from environmental management and lean manufacturing (Kurdve et al., 2014) may suggest that the relation between lean and green has to be considered on a detailed level in equipment and system design.

3. Method

The data collection method performed to carry out this study includes literature review and in depth interviews with equipment users. Literature review mainly focused on critical factors in designing lean equipment that a variety of scientific sources and books regarding lean production, equipment and eco-design were studied. A comparison of common lean principles, lean product development principles and eco-design principles was also carried out to derive lean and green design principles for equipment design.

Firm conclusions about the critical factors in designing lean equipment were not drawn from the literature study, instead the empirical data were used to extract the most important principles mentioned in literature. Empirical data in this study gathered through observation, open question user-related interviews and an industrial workshop/group interviews depicted in underneath table.

The data were cross-analysed with the results from literature studies to analyse companies’ requirements. The number of interviewees does not give firm verification of the research results, and further interviews with more users and with suppliers are planned in the commencing studies.

Table 1 - Related information to empirical studies

Code	Type of Industry	Type of study	Number of interviewees	Interviewees' Positions
A	Automotive	Interviews, Observation, Document review	4	Project Manager, Lean specialist, Maintenance engineer
B	Biopharmaceutical	Interview	1	Project Manager
C	Automotive	Interview	1	Project Manager
D	Automotive	Workshop Interview	3	Engineering manager, Project managers

4. Empirical results

4.1 Study A

The main case study in this research has been done in an automotive company through interviewing four key managers and engineers. Although there are several general guidelines for specifying the production equipment, maintenance, safety and agronomy, lean production and scope of supply, interviewees mention that there are no specific guidelines in designing the production equipment for Lean. A manager stated that they mainly analyze whether the equipment is easy to operate and to maintain. In addition, factors such as error proofing, reliable maintenance, safety of operators and support one piece flow were mentioned as analysis factors. One individual stated that the main basic factors in specifying the equipment are the cost, current situation, type of product and complexity of the product. A guideline should give different options with regards to volume, product type and complexity.

Regarding the production processes and cell layout, company A mainly consider the production processes to affect lean production implementation, not equipment design; although the strategy is to specify the equipment to support lean production. There is a part related to production processes in scope of supply, and also they test it in a pre-delivery test. One individual stated that although one piece flow is important from a lean perspective, it is difficult to achieve. Another comment was that it is critical to see how the material is brought into the cell from machine to machine; this influences the final layout.

Regarding the simplicity of equipment, one individual stated that "we rarely consider design of simplified machines, or maybe we do it but we do not know it." The specification of simplified machines is critical due to volume, cost and how many operators you need. Another main issue mentioned in specifying/designing new equipment is deciding on the level of automation which should be considered based on the cost and the budget. An important factor is whether the system can be run manually if the automation goes down or not. At company A automation level is decided in the pre-study and it is important to simplify in this step, otherwise problems with complexity may occur. Robots are more common than conveyors. The robot should be simple, it is not adding value to the part, and it is just handling the part. In addition, the human machine interface need to be simple. The reason for automation is to improve operators working environment.

One of the main factors is simplicity of machines to be easy to understand for operators. Also, they mentioned the importance of considering the distance between the machines in specifying the equipment. Likewise, visualization of working with machine is an important factor and can lower the complexity of machine. Furthermore according to an interviewee, combination machines add complexity, for example cutting and grinding in one machine give a complex machine that may be hard to operate. Another factor is to select the right size of electrical components. The optimisation has to be weighed against the need for standardisation of parts for different machines. In eliminating waste, service time is also important. Normally there is no manual backup for robots. If the automation stop, the whole line stop.

Regarding flexibility, one manager mentioned that they didn't have any guideline on how to specify portable and flexible machines. Volume and complexity of product are two critical factors in specifying portable and flexible machines. One individual mentioned that having portable machines is not an issue, but flexibility is a challenge. In the long run there is a need of a flexible production system. The machines should be designed for different variety of products and future changes in product type. In addition, supporting quick change over by equipment is critical because of small batches. It is important to minimize the setup time to eliminate waste.

In case company A, the parts outside the machine were mainly checked since specifying a machine which has capability of error proofing makes it more complex. This kind of machine needs to have several electrical parts which contradict to have simplified machine. In their point of view, it would be leaner if they check the parts outside the machine. When asked "Does the machine design support a standardized work sequence?" one said that they mainly implement the safety and ergonomic standard after buying the machine.

In interviewing a lean specialist, the importance of balance between one piece flow and number of components in a batch was pinpointed. For some processes like heat treatment, it is so difficult to have one piece flow. Based on her experiences, an important improvement is to make the setup easier on the machine. The flow between the cells need to be improved and machines should be designed to be easy to maintain.

4.2 Study B

The second empirical study has been done in a biopharmaceutical company. A manager responsible for specifying and buying equipment was interviewed who was specialized in lean implementation.

Regarding principles and guidelines concerning specifying and buying lean equipment, it was stated that there are top level principles but not in detail. When they bought the machine, it happens that something is missing from beginning. Since they spent so much money to buy machines, they need some specification to guide them internally. They do not want to have different engines in different machines since it is not easy maintain. They do not have a clear guideline regarding that. It is important for them to have environmentally machines and to know what should be common in the machines. He highlighted the need to imply the lean thinking in the start, since there are so much difficulties in implementing lean in the end. Further, he added that in process of specifying the production equipment, the critical issue is to meet recipe of product. The main lean factors in specifying equipment are mentioned as easy to clean, easy to maintain and easy to control. Small batches and short setup time are main issues in specifying the equipment. Also, since the priority in specifying equipment is recipe of product, buying an error proofing equipment is important.

Since company B has one supplier, they do not consider importance of simplicity in specifying equipment. The supplier usually supports a high level of automation. Regarding portable equipment, since they never change the layout, so having portable equipment is not an issue. In company B, the interface of operators with machines is considered. Although the machines are covered into a box because the product is poison, they consider that how much the operators walk between the two machines. They have also rule for distance between two machines.

The manager mentioned that although the process of analysing the old data is not standardize, they try to consider the old data. There is need of improvement regarding that. Likewise, they need to improve the process of test runs and the steps which they need to proceed before starting the production.

4.3 Study C

The third study has been done in an automotive manufacturing company producing prototypes of mechanical components. The first interview was with the key manager who specifies and purchase the production equipment.

While respondent was asked to mention the lean deign factors, flexibility of equipment, short lead time in setup and reducing the waste in changing the tool are stated as main factors. The big challenge in designing future machine is eliminating the stop time of changing tools. This has big impact on result of OEE and it is not almost considered. In this company, the main factor in buying the machine is the quality of product and the second priority is that the equipment should have a so high added-value per hour as possible as. This added value per hour is a key KPI for them. Based on these two main factors and other factors mentioned before, they evaluate the cost.

The main trend is to buy the equipment from the previous suppliers. After buying the machine, the equipment specification checklist is checked. They check factors such as uptime, environmental factors, etc. and make a full run test to make sure that it fulfills the demands. Although they produce high volume flow and one batch takes 24 hours per week, it is still one piece flow.

Robots are mainly used at company C and the problem is that the high cost of purchasing robots because of many reasons such as demand, quality, etc. but the operation is so simple. The complexity of equipment is a major problem. Furthermore, the manager mentioned that choosing a proper level of automation depends on type of products and operations.

Regarding the portability and flexibility at company C, the machines are portable and they can move the machine from one cell to another. Flexibility in the machine is related to fixture and they always need to rebuild the fixture. The machine is flexible more less when they buy it. Regarding the error proofing, they check the quality in the process since the machine with capability of checking the quality would be complex machine. As a result, in order to avoid this complexity, they check the quality in the process and apart from the machine.

Company C has guidelines for safety and ergonomic based on the law and they ensure to have a good working environment. As a manager mentioned, it is important to have a same system for all machine which makes it simple to learn. Hence, it is important to have the same programming in all machines. They have a system for monitoring the all machines.

In this company, they have problem regarding using the old experiences from specifying the old machines and this in an improvement area in this company. In addition, the manager highlighted the following potentials for improvements:

- Life cycle profit need to be measured in the machine, so there is a need for background data on the machine. For example if the company needs to buy similar machine, they should check how it was regarding the uptime and so on.
- The suppliers also should provide them with information that what type of running cost will be on the machine. This will be future work for them, to see which spare part they need to change and they can calculate the cost for that.
- The other improvements are: reduce waste in tool changing and minimize the setup time

4.4 Study D (Workshop Interview)

In an industrial workshop, a production engineering manager and some project managers answered that they use some principles in their workshop makeover. The makeover aims for a lean transformation of the plant and a number of design principles can be deducted: Straight flows, Visualisation, Safety and Teamwork are mentioned, and also Standardisation, Energy efficiency and Quality assurance. One project manager shows examples of straightening of flows and teamwork by layout changes, also ergonomic and safety improvements by simplification of the process were results. She meant that the principles used in the design of the production cell were increase teamwork communication, visualisation, straight flows, safety and general 'leanness'.

An example of design for visualisation: all meters for monitoring of a machine has to be visual for an operator standing at the side of the machine, i.e. no lids has to be opened, no bending or climbing to read the meters.

An example of design for teamwork: Machines are designed to be open towards a team area with no conveyors or other parts hindering communication with team members operating other lines/machines.

Example of design for quality assurance and energy efficiency: All parts of machines that may need cooling are designed to be connected to a common central cooling system to ensure that tolerances can be met at all times of the year and to recycle heat/cooling in an efficient way.

4.5 Summary of results

The empirical results are summarised in table 2, showing the critical factors and first priority mentioned in the four companies.

Table 2 – Summary of Results

Study Code	First priority	Critical Lean factors in designing the equipment
A	To minimize Cost	- Easy to operate - Error proofing - Easy and reliable maintenance - Safety of operators - Supports one piece flow - Being simple - Minimum cost - Considering the production processes and cell layout - Being flexible - Visualization
B	To meet product recipe	- Easy to clean - Easy to maintain - Easy to control - Error proofing - Using previous experiences - Energy efficiency
C	To have high product quality	- Supporting short setup time - Flexibility - Minimizing the waste of tool changes - Being portable - Being simple - Safety of operators - Energy efficiency - Using previous experiences
D	To reach "leanness" and teamwork	- Straight flows - Visualization - Safety - Teamwork - Standardization - Energy efficiency - Quality assurance

The results support a hypothesis of the importance of considering lean requirements in designing of production equipment. Especially specifying and designing production equipment. It also shows that there may be some links between green and lean equipment design.

5. Analysis and discussion

The empirical results points out that current practice is specifying lean requirements on equipment design is much less homogenous and standardised than the implementation of lean tools and operational principles. However, emerging from the analysis are some main lean design factors for production equipment. These factors are designing simple equipment, error-proofing, being portable and flexible, supporting one piece flow, supporting short setup time, easy and reliable maintenance, supporting the operator interface with machine, safety of the operator, supporting production processes and layouts, energy efficiency, easy to operate, minimum cost, visualization, straight flows, teamwork, standardization, quality assurance, using pervious experiences, easy to clean, and easy to control. One main theoretical premise behind this subject is the importance of user-supplier integration. The findings resulted in empirical study mirror those of the theoretical studies as presented in table 2. In Table 3 there is a categorization of the factors in terms of operational and strategic level. This categorisation is based on the lean principles (Liker, 2003) described in theoretical part.

Table 3 – Analysis of Result- Lean design factors for production equipment

Level	**Factors from empirical study**	**Number of interviewees**	**Factors from theoretical study**	**Related Lean Principle** (Liker, 2003)
Operational	Safety of operators	8	*	Principle 8
Operational	Being flexible, minimizing the waste of tool changes	6	*	Principle 4
Operational	Error proofing	5	*	Principle 5
Operational	Easy and reliable maintenance	5	*	Principle 8
Operational	Supports one piece flow - Supporting short setup time	5	*	Principle 3
Operational	Being simple	5	*	Principle 4
-	Energy efficiency	5	*	-
Operational	Easy to operate	4	*	Principle 8
Strategic	Minimum cost	4	*	Principle 1
Operational	Considering the production processes and cell layout	4	*	Principle 2
Operational	Visualization	4	*	Principle 7
Operational	Straight flows	3	*	Principle 2
Strategic	Teamwork	3	*	Principle 10
Operational	Standardization	3	*	Principle 6
Operational	Quality assurance	3	*	Principle 5
Strategic	Using pervious experiences	2	*	Principle 14
Operational	Easy to Clean	1	*	Principle 8
Operational	Easy to control	1	*	Principle 8
Operational	Being Portable	1	*	Principle 8

Furthermore, when the participants were asked about the process of specifying the equipment specification, the majority commented that the strategy of specifying the equipment specification depends on the target point. These target points differ from one company to another (Table 2). One of the issues that emerges from these findings is lack of holistic approach in specifying and buying the equipment. As stated, the main focus is to meet the target point and this triggers to lack of holistic analysis for selecting optimized alternative in buying equipment process. For example, the target point in company A is to minimize the cost and almost, the best alternative is selected based on minimizing the cost which is short term cost. With a strategic and holistic approach in aligning the all factors such as energy efficiency, being flexible, etc., the optimized option can be more expensive in short term but minimize the long term cost. Hence, it could conceivably be hypothesised that to select optimized alternative in buying the equipment, there is need of a holistic and strategic analysis in aligning the factors.

A suggestion for aligning the factors can be to set a score for each factor based on strategy of the company.

A hypothetical claim that needs further verification is the linkage between green and lean equipment design. It is shown that there is a need of holistic view on designing the equipment and aligning lean, green and cost factors. When designing the production process concept, it is important to consider the interface of each machine with the rest of the production processes, layout of the cell and the human organization. Although, this study builds on investigating the main factors of lean designed equipment, further research in this area may include aligning between three factors of lean, green and cost through a user-supplier integration concept.

6. Conclusion

The findings of the study lend some support to the claim that it is important for companies with a lean programme to consider lean principles in specifying and designing production equipment. It also shows linkage between green and lean equipment design. However common practice is not to use lean principles when specifying requirements on equipment.

In conclusion, some important factors for designing lean equipment are presented. Safety of operators, flexibility, quick changeovers, error proofing, reliable maintenance, energy efficiency and one piece flow are the ones most mentioned. Also, a holistic system view of the production system when designing the equipment and aligning the lean, green and cost factors is beneficial. In process design, it is important to consider the interface of each machine with the rest of the production processes, cell layouts, and with the human organization. Further research in this area may include aligning lean, green and cost through a user-supplier integration concept.

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Calibrating the expectation from corporate lean programs

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Abstract
Considering all the evidence in literature and industry, there is little doubt that corporate lean programmes has the potential to significantly improve the performance of manufacturing firms. Many multinationals have therefore recently launched their own lean programmes. Typical examples include the Audi Production System, Boeing Production System, Bosch Production System, Caterpillar Production System, Rolls Royce Production System and Scania Production System. However, how the expected improvement manifests itself during the implementation process is less clear. Using an in-depth case study of the Volvo Production System, this paper investigates how the performance of a plant change as it continues to implement a corporate lean program. The answer has important implications for how managers can successfully implement lean in a plant. Not knowing it can lead managers to set erroneous targets, have unreasonable expectations, and, worse, take improper actions.

Special track: no full paper

Offshoring trends in the manufacturing process within the automotive industry

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Abstract:

This paper investigates offshoring trends in the automotive industry. The research approach consisted of combining empirical findings from case companies with latest research from the field. Empirical data was collected through case studies from 15 automotive organisations based in Europe consisting of original equipment manufacturers and engineering service providers.

The findings indicated some offshoring trends in the automotive industry. Offshoring in this industry is moving from a manufacturing focus to incorporate large parts of the process, including high-level product development engineering activities. This development has created several challenges. These challenges arose as organisations are not considering how offshoring activities could be integrated with an increasingly global supply chain for the manufacturing of the final product.

The paper contributes to manufacturing theory with a focus on offshoring in the automotive industry and provides practitioners with information on a cutting-edge trend to the industry.

Keywords: Manufacturing, automotive industry, offshoring

1. Introduction

Recent years have seen a dramatic development in the manufacturing industry. With increased globalisation, cost pressures and greater competition, manufacturing of products has increasingly moved to low-cost countries.

The automotive industry has witnessed peaks and troughs with organisations reducing costs by outsourcing and offshoring the manufacturing segment of the product design and development cycle. Cost pressure has affected other areas of the product design and development leading automotive organisations to outsource and offshore complex engineering activities such as design and development which are now becoming an increasingly globalised commodity.

A number of organisations have offshored design and development activities (e.g. utilising their engineering captive centres) whereas other organisations have offshored to a third party provider based in a low-cost country. The globalisation trend of manufacturing in the automotive industry has been overlooked within the research community and only a limited amount of research exists. This paper investigates 15 automotive organisations and the approaches taken when offshoring the manufacturing part of the product development cycle. This paper examines different offshoring approaches that allowed a trend to be crafted for the automotive industry.

This paper presents a literature review followed by the methodology implemented to detail the case organisations. The findings from the research are then detailed and outlined followed by an analysis. Finally, a conclusion and notes for further research are presented.

2. Literature review

Outsourcing has become increasingly popular for organisations of every size and has attracted attention from researchers aiming to understand why it occurs, and practitioners to experiment and understand how the process can be optimized and implemented smoothly without occurring additional costs (Oshri 2009, Willcocks *et al*. 2011). However, Kotabe (1993) and Venkatraman (2004) have identified that the practice of outsourcing is not new and has existed over a number of years, with management using the practice as a common tool and outsourcing being a key issue that is discussed at board level (Quinn and Hilmer 1994). Offshoring and outsourcing development in engineering and design is still relatively new (Burdon and Bhalla 2005) and is driven by organisations seeking to reduce costs, improve time to market, shorten development cycle times and either use an offshore centre as surplus capacity support or capability development. Roth and Menor (2003) have identified that the offshore outsourcing of services requires further research in order to fully understand this complex phenomenon, since when organisations globalize their product development processes they are faced with significant challenges and inefficiencies that would not normally occur when outsourcing domestically (Graber 1996). The offshoring of services has dominated manufacturing due to information technology globalization allowing people to work in remote locations (McIvor 2010), the world becoming more connected (Friedman 2005) and manufacturing being researched independently in terms of product development and design (Thomke and Fujimoto 2000).

The global economic crisis of 2008 and the globalization of organisations have impacted on the automotive sector significantly (Cattaneo *et al.* 2010), contributing to both General Motors and Chrysler filling for Chapter 11 bankruptcy in 2008, Toyota posting losses in 2009, BMW experiencing significant profit reductions and Daimler, Fiat, Renault and Peugeot all experiencing losses. This has led organisations to reduce costs by downsizing their operations (Allen *et al.* 2013). In Europe, Spyker cars acquired Saab from GM, TATA Motors acquired Jaguar Land Rover, Geely acquired Volvo and most recently in 2014 Fiat acquiring full stake in Chrysler. Porsche, on the other hand, overcame the automotive crisis and in 2008 increased its stake in Volkswagen. By 2012, Volkswagen had acquired Porsche and it is now a fully owned subsidiary. These changes are not only forcing organizations to reduce costs, but to assign new global strategies for survival (Gottfredson *et al.* 2005) and to disperse global product development with manufacturing to further reduce costs (Eppinger and Chitkara 2006). The design and development costs of automotive vehicles are rising while gaining good profit margins has become difficult, forcing vehicle platform designs to become standardized across multiple car lines (Maxton and Wormald 2004) and to develop effective design solutions. One of the ways to do so has been to outsource an entire activity in order to reduce costs and retain competiveness (Quinn and Hilmer 1994).

The automotive sector has seen radical changes in terms of outsourcing and how firms have globalized their operations (Ghemawat and Ghadar 2000). Adding to the recipe of complexity in an automotive vehicle that contains around 10,000 to 15,000 components (Oliver *et al*. 2008) and around 50 to 60 per cent of the total cost of components comes from outsourced suppliers (Bresnen 1996). Therefore, manufacturing offshoring is regarded as a complex engineering product, mainly due to the interfacing of thousands of components (Tripathy and Eppinger 2007). The engineering design offshoring sector is growing and is estimated to be worth $750 billion per year globally, with only $10 to $15 billion being offshored (Hamilton 2006). However, by 2020 the estimated global engineering design offshoring market is predicted to reach approximately $150 to $225 billion, as the sector is expected to grow rapidly over the next few years (Hamilton 2006). Research conducted by Duke University in 2005 found that 36 per cent of organisations sent engineering services offshore, with 16 per cent contributing to the offshoring of design.

The outsourcing wave for ITO dates back to 1963 when an organisation called Electronic Data System agreed a contract with Blue Cross of Pennsylvania to outsource data processing services (Lacity and Hirschheim 1993). This marked the start of a process that demonstrated to other organisations the tangible benefits of cost reduction and productivity improvement. Comparing the automotive sector with ITO and BPO the offshoring trend is relatively recent.
The outsourcing offshoring wave started when Ford Motor Company started to produce the Ford Model T at Trafford Park Assembly Plant in England in 1911; the motivation behind this move was the reduction of transportation costs. In the 1960s, many organisations in the United States started to move labour-intensive processes to offshore locations to reduce the costs of goods and services (Stringfellow *et al.* 2008).

The global product development offshoring wave started in the 1990s, with organisations still developing this trend (Eppinger and Chitkara 2006). Product design is defined as a knowledge-based activity and generates the majority of value in services and manufacturing (Quinn 1999). Offshoring in engineering services initially started with cost reductions due to high labour wages in the developed world. For example, General Motors offshores engineering work to reduce costs, whereas Toyota’s perspective on offshoring is the ability to tap into the local market and build domain knowledge to improve quality, speed of products to market and strengthen the organisation’s competitive advantage (Chiesa 2000, Thondavadi and Albert 2004). Any organisation considering outsourcing has four independent options available, as indicated in Figure 1.

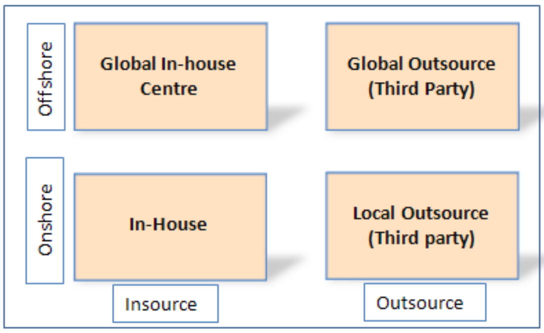

Figure 1. Outsourcing options for organisations. Adapted from (Eppinger and Chitkara 2009).

With reference to Figure 1, for an automotive organisation the options available are as follows. First, in-house: traditionally the most recognized and most popular, used when engineering design services are kept onshore and within the boundaries of the organisation.

Due to competitive labour rates and external pressure on organisations this option is now becoming unfavourable for organisations. Second, local outsourcing: also known as "third party", where engineering design services are offshored to an independent organisation with both having different strategic visions. This arrangement is beneficial for addressing short-term capacity constraints or when local skill is not available. Third, global in-house centre: still relatively new for engineering product design and offshoring, in principle engineering services are provided from an offshore location (in a developing country) where the centre provides services to the parent firm. Fourth, global packets and services are provided to onshore locations. However, it involves risks relating to data confidentiality and intellectual property rights.

A recent study conducted by Aron and Singh (2005) has identified that organisations that are involved in offshoring do not meet the financial benefits expected, nor do they understand the risks involved in outsourcing and offshoring. Organisations experience difficulties that mean up to half of the outsourcing contracts are terminated (Weidenbaum 2005), and in such instances this causes fears about job losses (Quinn and Hilmer 1994). When an organisation decides to offshore services, in this case engineering design or manufacturing, market conditions are changing so rapidly and if not fully understood could lead to management decisions on offshoring over a period of time being less cost effective and beneficial (Stringfellow *et al.* 2008). A further study conducted by Amaral and Parker (Amaral and Parker 2008) reviewed 100 outsourced platform design projects belonging to Fortune 1000 organisations and identified that these organisations struggled or failed due to a range of causes, including misaligned objectives within the organisation, unexpected rivalry and poor version control of documentation.

However, an organisation must fully understand that design outsourcing is probably the most complex within the outsourcing arena and if not completely understood may spiral out of control and fail to meet the cost savings originally anticipated. It takes management commitment to ensure that an outsourcing agreement is cohesively embedded within the offshoring model. There have been studies conducted by Quinn (Quinn and Hilmer 1994) that have identified that managers can easily become critics of outsourcing and quietly sabotage the relationship if they want to.

This literature review revealed that the automotive industry has seen significant changes and organisations have downsized operations or either merged or acquired organisations to maintain survival. Low labour rates have driven automotive organisations to set up low-production facilities overseas to produce vehicles at competitive rates rather than to import, thus attracting local customers and increasing both market share and portfolio awareness. There is limited research on offshoring manufacturing in the automotive industry and this paper will contribute to the research area by investigating the trends when automotive organisations are offshoring manufacturing services and further support practitioners to understand this phenomenon.

3. Methodology

This research focuses on understanding manufacturing offshoring in the automotive sector, something that is not well understood, thus leading this research to use a qualitative approach in order to explore the research question and provide rich, deep data (Oakley 1999). According to Gummesson (2000), when empirical data is collected from large organisations a qualitative approach provides good opportunities for obtaining the correct level of detailed information.

This research is case-based and includes three key phases: a theoretical phase, an empirical phase and a reflection on current theory based on new empirical evidence. First, an extensive literature review was carried out. Second, data was gathered from an in-depth case study and these findings were used to reflect on the current situation in the research field. Third, the theoretical and practical implications of the new knowledge were identified.

The case-study approach was selected as the most appropriate research methodology since offshore outsourcing is complex (Oberst and Jones 2006). The explorative nature of the research question allows for an in-depth understanding of the research object (Yin 1989), for theories to be developed and built into a model, and has become an increasingly accepted methodology for use in management and engineering disciplines (Gummesson 2000). The case-study approach delivers a rich in-depth study of a phenomenon where limited knowledge or extant knowledge seems inadequate in relation to the automotive industry being categorized as complex in terms of designing a vehicle due to the number of stakeholders involved (Maxton and Wormald 2004, Yin 1994). The case organisations were selected based on a number of key parameters including, (i) being an engineering organisation in the automotive industry, (ii) the organisation being global, (iii) possible access to management and post-senior management, and (iv) the offshoring of product design activities and manufacturing being present.

Interviewees were selected based on their experience with the organisation’s global engineering activities. VPs and senior managers from different areas were interviewed to understand the connectivity of the engineering activities with other functional areas. The main method of data collection was through semi-structured interviews that allowed the researcher to probe additional questions and illuminate the research study (Patton 2002). This approach also ensured that the researcher did not anticipate the interviewees’ replies (Berg 1998), thus leading to in-depth explanations that other interview formats will struggle to provide (Silverman 1993). In addition, the semi-structured interview style further allowed the researcher to request clarification on certain areas such as how the manufacturing strategy was developed, what the drivers involved when offshoring the manufacturing process and other aspects that were not so clear (Berg 2001).

The research involved interviewing both Original Equipment Manufacturers (OEMs) and Engineering Services Provider (ESPs) to further understand the drivers involved when organisations in particular OEMs outsource and offshore their manufacturing process to low-cost countries to take advantage of lower labour rates either in low-cost manufacturing or smaller kit assemblies producing a product. To ensure organisations were correctly targeted a screening process was used upfront in order to conduct a critique analysis on offshoring the manufacturing and design process. The use of secondary data, including other confidential information received from the organisations after signing a number of confidentiality agreements, allowed the researchers to target precisely different organisations.

In total, 25 in-depth interviews were carried out in 15 automotive organisations lasting between one and three hours, as illustrated in Table 1. To comply with ethical conducts all organisations have gone through an anonymity process. The majority of the interviews were face to face either onsite or offsite at discreet locations, and a small number were conducted via telephone due to availability reasons.

Company	OEM & ESP	Interviewees	Duration of interviews (hours)	Experience (years)
1	OEM	CEO, VP	1.5	20
2	OEM	VP	2	15
3	OEM	VP, Director, senior management	2.5	18
4	OEM	CEO, Director	1	15
5	OEM	Director	1.5	5
6	OEM	Director	1	8
7	OEM	Post senior management	2.5	9
8	ESP	CEO, Director	1	11
9	ESP	VP	2	12
10	ESP	VP, Director, Various post senior management positions	3	9
11	ESP	CEO, Director	1	18
12	ESP	Director	3	10
13	ESP	Post senior management	2.5	6
14	ESP	VP	1.5	6
15	ESP	VP, Senior consultant, senior management	3	25

Table 1. Interviews mapped against experience and durations.

All interviews were transcribed and recorded when allowed, which ensured validity and quality in the empirical data (Legard *et al.* 2003). All interview data has been coded using NVivo 10, a qualitative software package. The interviews were transcribed followed by a rigorous coding procedure. Open coding techniques were first applied that generated up to 400 codes which were further reduced by applying selective coding techniques that concentrated on the themes. The coding steps are shown in Figure 2. A cloud analysis has been created from the codes using NVivo in order to further understand word frequencies and narrowing the selective coding approach, thus achieving the 10 themes as illustrated in Figure 3.

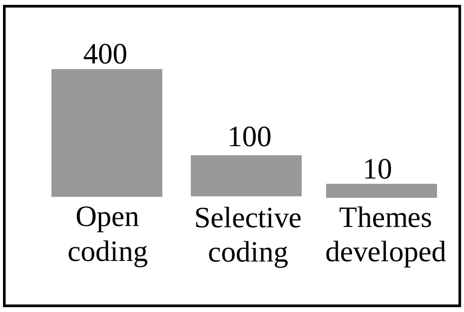

Figure 2. Coding process.

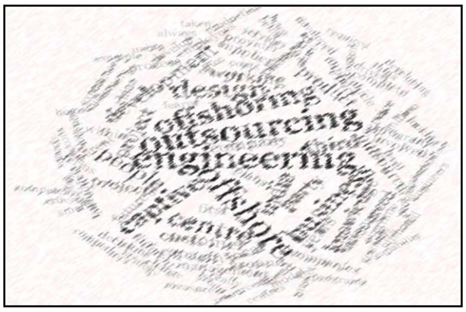

Figure 3. Word cloud analysis NVivo.

Additional information was collated in the form of company archival documentation, strategy documents and public statements to ensure an accurate representation and enabled triangulation of the findings between different sources of information to improve validity (Mason 2002).

All the case companies were large global organisations in the automotive industry which are amongst the biggest players on the market. Seven of the organisations were OEMs while eight were ESPs to the automotive industry. This gave a more holistic perspective on outsourcing transactions and in-depth information regarding offshoring activities. The OEM companies all had headquarters in Europe to lessen the difference in culture between the OEMs for the purpose of this research. The ESP companies were a mixture of engineering service providers and first tier suppliers providing engineering services such as new product development, concept car development and new facility start-ups in both automotive and aerospace industries. They had engineering centres located in low-cost countries, mainly India and China, which provided low-cost offshore engineering services to global organisations and the local market.

4. Findings

The findings from the case organisations identified how offshoring was conducted for this industry. The increasing demand to reduce cost, develop new market penetration, and globalisation within the automotive industry has led organisations to progress new thinking and new ways to increase revenue while maintaining the correct quality levels when offshoring and ultimately reducing costs. The organisations interviewed for this research first offshored manufacturing to low-cost countries namely China and India to take advantage of labour arbitrage and the educated workforce. Over several months of operating their manufacturing processes, the organisations with caution started offshoring routine engineering tasks to either their own offshore engineering centres or a third party service provider based locally.

In recent years high value adding engineering product development tasks have been relocated to low-cost countries. The resulting products are not only sold on the local low-cost markets, but due to capacity constraints and the costs involved with setting up a new facility, these products are also sold to other markets such as Europe and North America. A key driver for organisations to distribute the local products globally was the experience the organisations gained with offshoring.

However, the technical capability in offshore locations caused challenges for organisations who are implementing such strategies. Communication challenges between onshore and offshore locations created misunderstandings that were interpretatively different to the outcome, virtual communication and communication across cultures was difficult and resulted in a consequence of delays that affected the perceived quality of the product. Knowledge sharing was another challenge when the organisations offshored the manufacturing process. The physical (and in some cases organisational) distance and differences in the work approaches due to different cultures meant that trusting one and another was difficult to establish and the knowledge required to develop a fruitful product for the home location. Furthermore, the onshore organisation assumed that their counterparts in the offshore centres or within the offshore outsourcing provider already had the know-how and knowledge to develop the product. Thus, the organisations did not fully share this information which was either culturally or organisationally based and therefore not general knowledge.

The organisations faced these challenges as there was a lack of planning the offshoring and outsourcing process in detail before making the decision. This approach led to unforeseen impacts which were difficult to handle and financially impacted the offshoring contract. Furthermore, the impact on the supply chain and a detailed cost benefit analysis had rarely been conducted. This meant that unforeseen consequences from suddenly having to wait longer on some parts, language barriers or cultural differences were ignored or not considered as being important.

The organisations that were interviewed as part of this research reacted differently to these challenges which have been categorised in three separate segments:

Segment 1 - Roll-back: *Pull back all most the most basic and routine engineering tasks to locations in high-cost countries.*
Segment 2 - Control: *Increase supervision and control with the offshore operation/third party.*
Segment 3 - Collaboration: *Increase knowledge sharing, build trust and develop increased interaction between the organisations.*

The first segment focused on the perceived uncertainty and damage by pulling back the globalised operations. The second segment consisted of frequent interaction; control with access to software, controlled information flows and divided tasks (meaning that the team abroad would not know the details about where the element/part they were working on would fit in with the final product). The third segment was the opposite of segment two as the organisation would openly debate the differences and difficulties and address them through increased dialogue, trust building events and exercises, company visits and virtual knowledge sharing platforms.

The case companies' reaction depended on several unique organisational factors such as their strategic goals with the offshoring or outsourcing endeavour organisational culture. While the first segment meant moving back to have a few operations globalised, both segments two and three were successful for some of the companies that implemented them. The successful companies were those where the organisational culture and strategic goals which aligned with the solution approach they implemented. An example is that a company which was focused on collaboration did not succeed with the second solution strategy if the outcome was a complex engineering task.

5. Analysis

Our findings from the automotive industry confirm previous findings that a small number of organisations know how to evaluate risks associated when dispersing engineering functions and tasks to offshore locations (Kumar *et al.* 2009) and as a consequence complications arise. The findings also support previous findings that the main risks include cultural differences and knowledge transfer (Rottman and Lacity 2008; Kotlarsky *et al.* 2008). This is supported by Carmel and Beulen (2005), discovering that unsuccessful knowledge transfer is one of the principal reasons for failure. Culture is a big risk factor as it influences communication, quality, knowledge sharing and many other aspects of management critically required to ensure a successful offshoring strategy (Kull and Wacker 2010; Hall 1983). The complications are often due to the interaction intensity and interaction distance between the company and the organisational unit (Stringfellow *et al.* 2008). Interaction intensity consists of service content and service process. Interaction distance is based on the distance between cultures, languages and geographical distance.

We can therefore conclude that the automotive industry has followed a similar path to other industries when it comes to outsourcing and offshoring trends. However, while the automotive industry has had many years to master a global supply chain in terms of manufacturing and management of suppliers to their factories, only recently organisations are globalizing complex engineering activities. The globalizing of complex activities has developed additional challenges for organisations to incorporate these elements into their supply chain.

This research has discovered some critical elements which can assist automotive organisations in their offshoring process:

Know your goals - *Spend time debating inside the organisation what increased globalizing means for the company and why it would be a good idea. Create a cost-benefit analysis and be certain this is the right step at this time.*

Plan the offshoring/outsourcing move - *When deciding to start offshoring or outsourcing or increase the current level (e.g. move more out), importantly plan the process and consider possible obstacles before the strategy is changed.*

Plan for the whole supply chain - *Having a more globally diverse supply chain means a more complex supply chain that requires additional attention, control and coordinated planning. Any changes in relation to offshoring and outsourcing must consider the impact on the supply chain and not a singular object.*

When an organisation decides to offshore activities, attention must be given to communication and transparency, when deciding to increase the offshore content or starting a new globalized activity.

This is vital for ensuring that everyone affected understands the process, its goals and the desired outcomes, e.g. 'why' and 'how'. The organisation needs to align its focus and efforts across multiple layers in order to ensure all processes and procedures have a common objective and outcome.

An offshore engagement can become rather skewed into one direction and lose traction if constant measures or progress are not implemented along with performance indicators to track the health of the offshore engagement ensuring objectives originally outlined are being met. If these steps are overlooked in an organisation, it becomes more difficult to measure processes, quality and to determine whether the desired outcome is achieved within the globalization process.

In order for a product to be created successfully when work streams are dispersed across several global locations, management must adopt cross-cultural project management processes and focus on knowledge management, both within the organisation. If external third party service providers are contracted the key stakeholders can share the correct information with the relevant people. While unofficial knowledge sharing can help align projects with targets within organisations, physical and cultural distance creates additional complexity when the product is developed in different locations. Therefore, written procedures and a clear knowledge-sharing culture with embedded knowledge-sharing activities are vital to ensure knowledge which can be codified is embedded across all locations. Furthermore, it is important to embed the decision process in the organisation and ensure risks and benefits are carefully weighed, planned, managed, controlled and continuously aligned as new information surfaces. The particular connectivity of these factors is essential when an organisation needs to reduce the risks associated with a global manufacturing supply chain that increasingly covers all steps of manufacturing; from initial design to the manufacturing process itself.

Outsourcing or offshoring cannot be viewed or implemented as an overnight quick-fix tool for an organisation due to the high complexity and risky nature, as well as requiring a well thought out and detailed plan. If automotive organisations incorporated these elements in their global decision process they could reduce the risks identified in this paper when outsourcing and offshoring by planning, preparing and incorporating the new globalisation elements into the strategic and operational levels of the organisation.

6. Conclusions and notes for further research

This paper investigated the globalization trends in the automotive industry. The findings show that offshoring is no longer limited to low-cost activities. Increasingly, product design and product development is being offshored to low-cost countries, for instance China and India to reduce cost and improve the product development cycle time. This development has created challenges relating to culture, communication and knowledge sharing. These challenges were identified as organisations overlooking how offshoring activities were to be integrated within the increasingly global supply chain for manufacturing of the final product. The case companies reacted in three different ways to these challenges depending on several unique organisational factors as their strategic goals with offshoring or outsourcing endeavour organisational culture:

1. *Roll-back.*
2. *Control.*
3. *Collaboration.*

The findings crafted a timeline for offshoring trends in the automotive industry. Automotive organisations initially start with a simple manufacturing facility in an offshore location to gain local product knowledge and have the ability to sell products locally. Once the manufacturing facilities have been established and run for several months, organisations will either open an offshore engineering centre or engage with a third party provider to support the facility. The engineering centres will work on providing local support to customers in particular original equipment manufacturers. The findings also reveal that when organisations offshore product development they initially start with simpler tasks which progress to higher complexity only after the desired capabilities and competences have been achieved.

We suggest some key elements which could assist automotive companies in their offshoring process which are outlined below:

- *Know your goals.*
- *Plan the offshoring/outsourcing move.*
- *Plan for the whole supply chain.*

This paper contributes to manufacturing theory with a focus on offshoring in the automotive industry by discovering new knowledge and insights to this field. Further, the paper will give practitioners a useful introduction to trends in this industry.

Further research is needed in order to (1) validate these results across countries and with further automotive organisations, (2) a further understanding on why some organisations succeed and others fail when offshoring manufacturing and design, (3) analyse the impact of each challenge (for example is cultural distance a larger or smaller challenge compared to the physical distance) in order to determine the most costly challenges, and (4) compare these findings with other industries.

This paper contains research limitations; the research is based on interviews conducted within the automotive industry and therefore the conclusions drawn may not be full generalized. Future research in the area requires investigating and testing the results.

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Re-shoring UK Manufacturing Activities, Supply Chain Management & Postponement Issues

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Abstract

As a result of globalization and dynamic business environment, manufacturing sectors are obliged to co-operate within more complicated and longer supply chains. Therefore since the mid-20th century, offshoring trend for manufacturing facilities has gained significant popularity to reduce cost. However over the past years, the evidence shows that offshoring strategies may not continue to be beneficial for the organization's manufacturing activities. Companies have begun to establish a better understanding of the total risk/benefit-balance and base their decisions on strategic supply chain issue rather than simply relying on cost analysis. Consequently it is evident that there are tendencies on reversing the off-shoring strategy and re-shoring manufacturing activities. Despite the significance of this phenomenon, the supply chain literature has not received sufficient attention by the academic community. This study aims to identify the supply chain criteria, which influence the manufacturing decision-making process and investigate the applicability of postponement in repatriated manufacturing activities.

Key Words: Re-shoring, Supply Chain Management, Reinvented Manufacturing, Postponement

Introduction

In today's world, due to the globalization, the manufacturing sectors are obliged to work within far more complicated and longer supply chains than in the past which allows them to remain competitive in a dynamic market. The businesses ought to restructure their supply chain according to the global configuration in order to access to cheap labour, raw materials, larger market as well as take advantage of the incentives offered by the host governments for foreign investments (Manuj and Mentzer, 2008). Consequently the trend for expanding and contracting across the globe has become popular across the industries to ultimately reduce the production cost and gain competitive advantage. This involves strategic planning in terms of sourcing from locations that offer the least procurement rates, moving manufacturing and assembly to the low-cost countries and finally marketing it in regions that have the highest potential customer demands (AlHashim, 1980).

As a result, the industries started to shift their productions to the low-cost countries, namely Eastern Europe and Asia, since 1990s, which is commonly known as "Offshoring" (Corino, 2009). This trend began by moving the low-skilled jobs such as simple assembly processes for high volume commodity type products to the developing countries nonetheless at present with the help of communication technologies as well as easier access to educational channels, these developing countries are now capable of providing a far more sophisticated labour forces. As a result of this, there has been a dramatic decrease in manufacturing jobs in some of the western countries such as USA, Germany and UK (Herath and Kishore, 2009).

However according to Fine (2013) during the recent years “the big names at the end of the chain have come to realize that the lowest price can mean highest risk – and highest risk can mean high total costs”. Consequently when it comes to manufacturing location decisions the industries have begun to pay more attention to unquantifiable factors such as the supply chain issue and strategic factors rather than simply relying on cost (Fratocchi et al. 2014). This highlights the significance of brand reputation and the risk of companies being exposed in the transparent global supply chains imposing companies with more ethical and long-term manufacturing location decisions (Ellram, 2013). Having considered the discrepancy between the initially estimated cost of offshoring and those of actually occurred resulted from the “hidden costs”, it is evident that there are tendencies on reversing the off-shoring strategy (Gray et al., 2013). This has led the companies to perform rigorous risk analysis considering the total cost and take the supply chain perspectives into account when making manufacturing location decisions and not solely rely on cost aspects of the production (Ellram et al., 2013). Nonetheless it is essential for the company to perform an in-depth research to identify the risks associated with their location decision as well as outsourcing and insourcing strategies.

It is evident both in the literature as well as the media that the new generation of the industries and jobs that are coming back will be different to the ones that were previously offshored which were mainly labour intensive activities (Fine, 2013, Bardhan, 2014, Baxter, 2014). Due to these changes it is believed that the only way for a long lasting and a sustainable re-shoring strategy is fundamental transformation of the current industrial production. In a report written by Tata Consultancy Service, these transformations are called the “Reinvented Manufacturing” (Tata Consultancy Service , 2013). Meanwhile PA manufacturing group claim that quality and costs issues are unlikely to be the reason for the long-term repatriation of production from low cost countries (Lawrence and Vasak, 2014). Consequently seven mega-trends were recommended by Tata Consulting Service to be adopted as a new direction of manufacturing industries (Tata Consultancy Service , 2013). As a result, the direction of this study was determined to assist industries and integrate the new generation of technologies within manufacturing activities. This study aims to investigate the relationship between re-shoring phenomenon and the postponement strategy and assess the applicability of postponement within the companies that have repatriated their production activities.

In this research an exploratory literature review has been conducted to provide a better understanding of the term re-shoring which is commonly used in the media, white papers and academic literature. The paper starts by providing a brief explanation of the concept of re-shoring. In this section various types of re-shoring are introduced. After that the main motivations behind the re-shoring are discussed. This includes the quantifiable and unquantifiable costs. The next part discusses the nature of new technologies coming back to the developed countries. This study focuses on the postponement strategy, which is one of the enablers of new generation of technologies. In other words “Postponement is a strategy to intentionally delay activities, rather than starting them with incomplete information about the actual market demands” (Yang et al., 2004). Hence a brief background on postponement is included. Figure 1 illustrates the direction of this research study and the main areas that will be discussed. Last but not least the final section of this report includes a methodology that will be used to carry out the research and obtained its objectives.

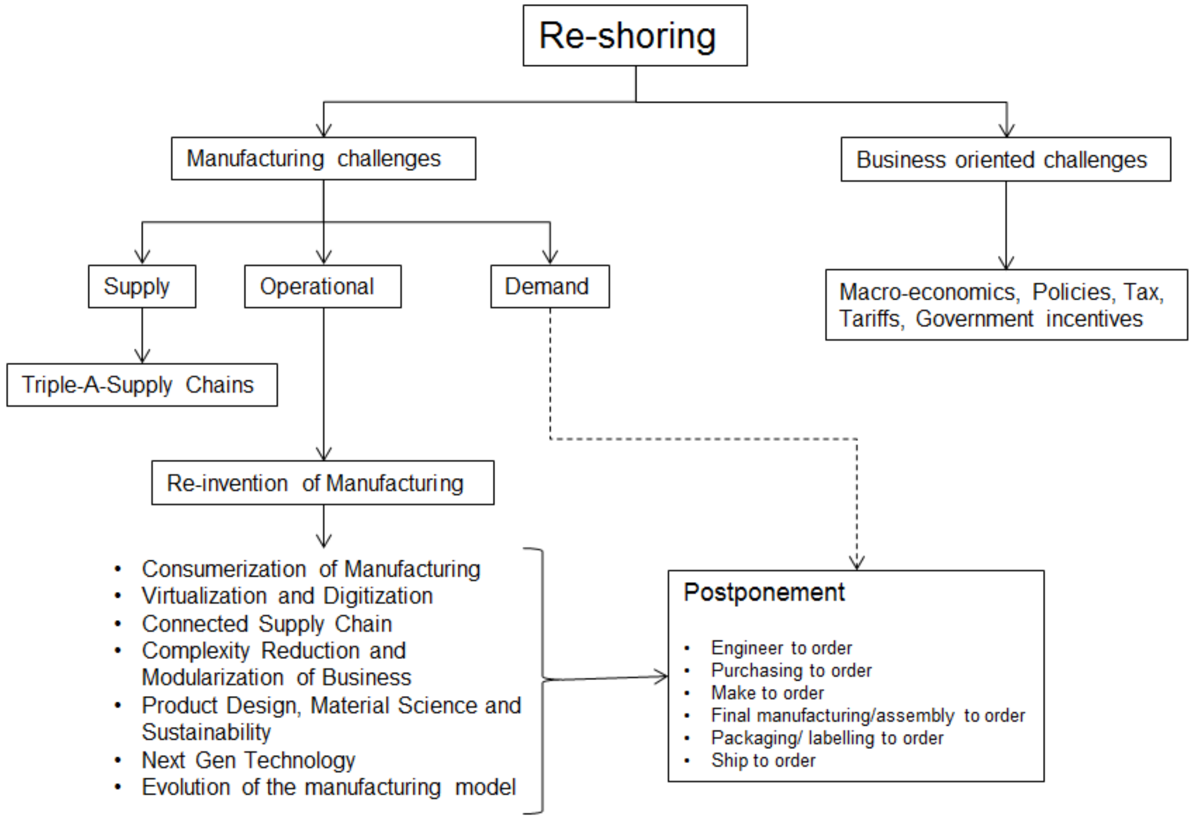

Figure 1, Research direction

Research objectives

The re-shoring phenomenon has come to attention in the UK only in the last couple of years through media, white papers by the consulting companies and limited number of academic papers. Therefore this concept is still in its infancy and has not been well investigated by the scholars. This study focuses on the postponement strategy within the context of re-shoring. The followings objectives have guided the execution of this research project. These objectives covers a broad range of issues related to the supply chain management which will be studied using case study approach explain in the “Methodology” section.

- To find out why the re-shoring is currently occurring and what are the risks associated with the supply chain reconfiguration
- To establish a good understanding of the technologies coming back to the developed countries
- To understand the relationship between the re-shoring phenomenon and the postponement strategy in the automotive sector
- To determine how and where the postponement can be used to assist re-shoring
- To evaluate how postponement can reduce the supply chain management issues in the context of re-shoring

- To identify the obstacles for postponement application within the industries coming back

Re-shoring or Back-shoring

In the current year, the companies have begun to establish a better understanding of the total cost and base their manufacturing location decisions on supply chain issue and strategic factors rather than simply relying on cost (Ellram et al., 2013). For this reason the decision on reversing the previous offshoring strategy has gained substantial momentum. However, despite the significance of this phenomenon, the supply chain literature has not received sufficient attention by the academics (Ellram 2013). Therefore due to the immaturity of the concept, several names have been dedicated in the existing literature such as “on-shoring”, “back-shoring, “home-shoring”, “Re-distributed Manufacturing” and “repatriating manufacturing” (Kinkel and Maloca, 2009, Fratocchi et al., 2013, Tavassoli, 2013).

It is evident in the literature that reversing the offshoring decisions is not a new phenomenon. There are number of studies performed under different titles such as “De-internationalization” and “International divestment”. Benito and Welch (1997) define De-internationalization as any activities, voluntary or compulsory, that decreases a company’s engagement in present cross-border activities. The analysis in this study was carried out from three theoretical perspectives: economic, strategic management and internationalization management. On the other hand the concept of International divestment defines the reduction of level of ownership in company’s direct foreign investment regardless of decision voluntariness (Boddewyn and Torneden, 1973). However these concepts, De-internationalization and International divestment, are lacking some of the key features of re-shoring phenomenon such as outsourced production. Another factor that these studies do not particularly demonstrate is the relocation of the facilities to the home country.

One of the most recent studies that investigate the offshoring reverse decision was conducted by Gray et al., (2013). In this study the term “re-shoring” was used where the major emphasis was on the location decision and their consequences in the American manufacturing companies. According to Gray et al., (2013) “Re-shoring, as such, is fundamentally concerned with where manufacturing activities are to be performed, independent of who is performing the manufacturing activities in question – a location decision only as opposed to a decision regarding location and ownership” (Gray et al., 2013). Moreover it is emphasized that the re-shoring should be assessed as a reversion of a prior offshoring strategy rather than in isolation. Another study, using the term re-shoring, was done by Ellram et al., (2013) where re-shoring is defined as “moving manufacturing back to the country of its parent company”. This study likewise uses the data from survey among the American companies to explore the reasons that influence the organization manufacturing location decision in United States. In order to establish better understanding of the location assessment, the factors influencing these decisions according to various regions are investigated. The results obtained from this study states that the importance of supply chain characteristics varies according to different regions across the globe. However it is important to note that the findings in this study only focuses on the wholly owned manufacturing facilities in foreign location and does not address the scenarios such as re-shoring the products that was previously outsourced to other foreign suppliers.

The term “Back-shoring” is an alternative name frequently used in the recent literature to refer to re-shoring phenomenon. Kinkle and Maloca (2009) are amongst the scholars that have made major contributions to this concept. According to Kinkle and Maloca (2009), Back-shoring is defined as process of returning full or part of the production from fully own facilities in foreign location or a foreign supplier to the company's domestic site. Unlike other studies performed by other researchers, in this analysis, Kinkle and Maloca (2009) claim "Back-shoring activities are predominantly short-term correction of prior misjudgment in offshoring decisions rather than long-term adjustment to chaining conditions at the foreign location". This study was carried out based on the data obtained from German Manufacturing Survey 2006 (Fraunhofer Institute of System and Innovation Research). One element that has not been mentioned in this study is the voluntariness of the Back-shoring decision. For this reason, study done by Fratocchi et al., (2014), which coined the term "Back-reshoring", proposes a unified and operative definition. According to this study Back-reshoring is "a voluntary corporate strategy regarding the home country's partial or total relocation of (in-sourced or out-sourced) production to serve the local, regional or global demand". In order to identify the main features of re-shoring phenomenon, Fratocchi et al., (2014) have used a comparative analysis of the re-shoring definition found in the existing literature. As a result of this study, three main characteristics of re-shoring concept were found. Firstly, it is a reverse decision of the once offshored facilities. Re-shoring does not essentially mean repatriation or closure of the entire production facilities in the offshored location. And finally re-shoring decision determines the relocation of the facilities back to the home country regardless of the ownership mode (In-sourcing and Out-sourcing) (Fratocchi et al,. 2014).

Types of re-shoring

The re-shoring phenomenon can occur independent to the facility ownership. This includes both in-sourced and outsourced productions. Therefore the manufacturing re-shoring can be considered from the both firm boundaries, in-sourcing and outsourcing, and geographical boundaries, firm's home country and foreign country, perspectives (See Figure 2). As a result, four possible re-shoring options can be identified. The first strategy is called "In-house re-shoring" where the company supply the demands in their domestic market by repatriating the entire or part of their wholly own manufacturing facilities from the foreign country to a wholly own facilities in the UK. The second strategy is "re-shoring for outsourcing" in which the companies meet the demand in the local market by shifting the manufacturing activities from a fully owned manufacturing facilities from the offshored location to a UK based supplier. Therefore the supply is transferred from in-house production to outsourced supply. The next strategy is "re-shoring for insourcing". In this option the company satisfies the demand by changing the companies sourcing strategy from offshored suppliers to a fully owned manufacturing facilities in the home country. And lastly is "outsourced re-shoring" where the change is only in geographical boundaries. In this strategy the firm convert their supply mode from offshored suppliers to UK-based suppliers. However these four strategies are different from each other but they share the element of location decision.

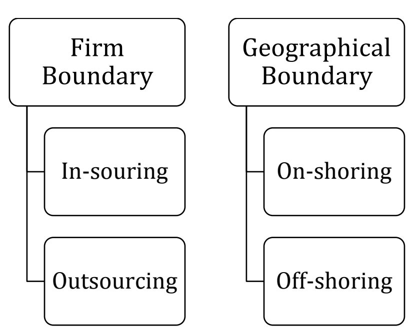

Figure 2, Re-shoring Options

Motivations for re-shoring

According to Leibl et al., (2009), most of the offshoring decisions are taken without evaluating the clear picture of its costs versus its benefits. This leaves the companies with the problem of facing various unexpected costs also known as “hidden costs” (Ellram, 2013, Leibl et al., 2011). Figure 3 represent the main motivations (hidden costs) behind the re-shoring decisions. The occurred costs can be classified into two main categories namely the quantifiable and unquantifiable costs. However according to the study done by Leibl et al., (2011), the significance of these costs influencing the re-shoring decisions, varies according to different countries. For instance in the past two years, ongoing studies have been performed to investigate the feasibility of the re-shoring strategy within the UK. Based on the latest Manufacturing Advisory Service Barometer, the costs, quality and reducing delivery time were recognized to be the main three reasons respectively, driving the re-shoring decisions in the UK (MAS, 2013). Nonetheless these factors for the French companies appear to be different to that of the UK. According to Clever Age (2006) the most important factors for the French industries were the transport and operational costs followed by the quality and lack of internal competence (Clever Age Digital Architecture, 2006). However Figure 3 shows the factors that can be applied for the majority of the companies regardless of where the companies are based. The middle section represents the costs that can be calculated but are not entirely under control of the companies. These factors appear to be influenced by the governmental decisions and political situations.

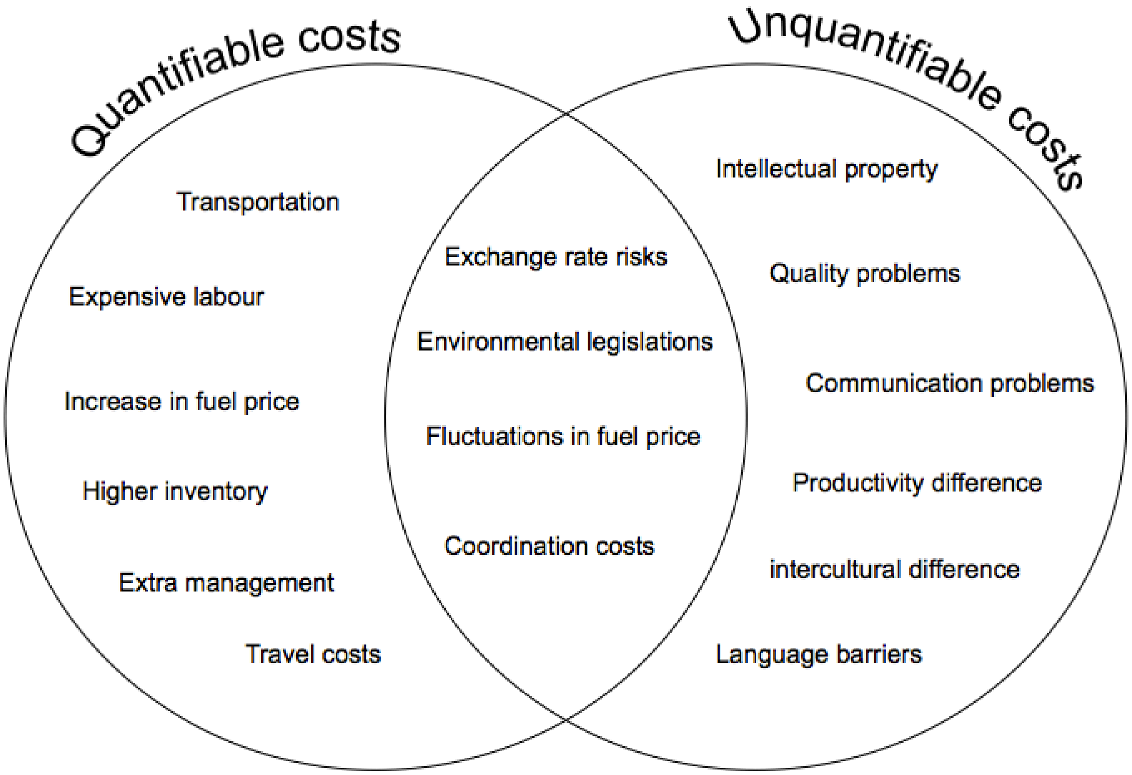

Figure 3, Quantifiable and Unquantifiable costs

Nature of new technologies coming back

In today’s world, the manufacturing industry is experiencing a significant change in business ecosystem as a result of ever-increasing complexity in customer behavior, technological development as well as competitive environment (Tata Consultancy Service , 2013). Due to this reasons PA consultancy group claim that quality and costs issues are unlikely to be the reason for the long-term repatriation of production from low cost countries (Lawrence and Vasak., 2014). Instead it is believed that the only way for a long lasting and sustainable re-shoring strategy is fundamental transformation of the current industrial production, which is called the “Reinvented Manufacturing”. In other words, it will not be economically feasible to repatriate the same manufacturing tasks that were previously offshored due to factors such as being labor and energy intensive. Therefore the new generation of manufacturing activities is required to adopt modern technologies by which the industries will ensure their competitive position in the market. One of the major focuses in the concept of Reinvented Manufacturing, is the personalization of the product by moving from mass production towards mass customization in order to address the ever-changing customer expectations. By doing so the industries can achieve higher variety while keeping the volume low. It is also aimed to reduce the time to market and have a more flexible production by employing new technologies and materials.

In modern manufacturing, the organizations should collaborate from all around the world to cope with the dramatic changes in the market. Physically distributed manufacturing architecture and teams is another enabler for reinvention of manufacturing that combines the organizations from different locations which allows them to contribute their main capabilities into the business. The temporary alliance of these businesses can be managed by utilization of systems that integrates all the organizations involved in the business. In order to develop such environment virtual enterprise can be utilized. The virtual enterprise is the collaborative networks of businesses that share their core competencies in order to pursuit a mutual goal, which is to respond to business opportunities. For instance, in such collaboration, one organization takes the responsibility of product deign whilst the other provides the manufacturing data supports. In order to develop a virtual enterprise and distributed manufacturing architecture, it is vital for the business to establish an appropriate partnership with the involving partners to ensure the fastest respond to the market changes. The establishment of the rapid partnership is based on the partner’s delivery capabilities, the quality of the products, infrastructure and the level of their dependability to IT. The key objectives of forming a rapid partnership would be to integrate the technical knowledge as well as marketing skills in order to remain competitive against other manufacturing organizations (Gunaskaran, 1998).

According to the PA Consulting group the reinvention of manufacturing will provide new business opportunities and models for the home based local manufacturer. Among these new technological opportunities, big data, intelligent robots, 3D printing and self-assembly Nano machines and utilization of new materials such as nanotechnologies, cyber materials and green plastics were mentioned (Lawrence and Vasak., 2014). Meanwhile another study conducted by Tata Consultancy Service (TCS) states that the future of manufacturing needs to be aligned with seven mega trends in order to address problems caused by the evolving technological landscape. These mega trends are as follow:

- Consumerization of manufacturing. In other words shifting the focus from Business-to-Business (B2B) to Business-to-Business-to-Consumer (B2B2C). This involves establishment of customer-centric business system using interactive websites, digital marketing channels, Point-of-Sale (POS) systems, e-commerce.

- Virtualization and Digitization. This comprises the utilization of software to simulate, visualize, and virtualize the product behaviour and performance under virtual scenarios. Hence it enables the companies to achieve more products testing iteration within a shorter time resulting in a quicker time-to-market. The Cloud technologies can be considered as one of the way to initiate such collaborations.

- Connected Supply Chain. A network of interrelated supply chain that can also provide high visibility from suppliers to distributors. This would allow the companies to develop an agile production plan meanwhile maintain minimum inventory.

- Complexity Reduction and Modularization of Business. Modularization can be applied in various aspects of the business, products as well as processes. For instance by adopting standardization and harmonization, companies can ensure component economies of scale since similar components across product families will be used which also facilitates product updating. Moreover it increases the product variety and also reduces the order lead-time due to fewer components.

- Product Design, Material Science and Sustainability. This trend investigates the application of the new generation of materials with higher performances, lower costs and environmentally friendly. Moreover, companies are also obliged to consider the carbon footprint from supply perspective by intelligent sourcing and shortening the supply chains.

- Next Gen Technology. This includes the utilization of embedded electronics, telematics, mobility, telecom services, and conventional engineering systems.

- Evolution of the manufacturing model. This indicates the requirement for a shift from large centralized companies to a network of smaller modularized businesses that offer their core competencies and are closer to the end customers (Tata Consultancy Service , 2013).

As a result of these mega trends mentioned above, the business processes should be transformed in order to adapt to the new technological changes, organizational policies are reworks and meanwhile the people are expected to think and perform differently to these transformations. The following section introduces a strategy, which can potential address some of the mega trends recommended by the Tata Consultancy Service.

Postponement in the context of Re-shoring

Once the repatriation of the manufacturing activities back to the home country has occurred, the companies are required to develop an effective management strategy for their new supply chain layout that can creatively integrate and perform the logistics and production activities (Pagh and Cooper, 1998). Meanwhile, customers demanding for higher levels of product customizations have put the manufacturing industries under substantial cost pressures for having to deal with shorter product lifecycles. This requires an accurate planning and product demand forecast. However as the time passes this task is becoming more complex and risky. Hence alternative supply chain strategy called postponement is being widely used to minimize the issue caused by the uncertainties (Yang and Burns, 2003). Postponement was initially viewed, in marketing literature, as a strategy to reduce the risk and uncertainty costs associated with the differentiation (form, place, and time) of goods (Alderson, 1950). According to Yang and Burns (2003) "Postponement centers around delaying activities in the supply chain until real information about the markets are available". This strategy can be applied in product design, process design and supply chain management (Van Hoek et al,. 1999). There are numerous studies performed, investigating different aspects of postponement both in business and marketing as well as production management literature where earlier studies can date back to 1965 (van Hoek, 2001). These studies mainly identify where, when and how to implement the postponement strategy (Yang et al,. 2005). Despite of having a well-established literature available, currently, the applications of the postponement strategy are still at an infancy stage (Battezzati and Magnani, 2000, Yang and Burns, 2003). Therefore it is evident that the application of the postponement is expected to increase within the industries (Yang et al., 2004).

Future Work

It is evident in the literature that since 1980 the number of scholar employing empirical studies within operations management studies has increased significantly (Rungtusanatham et al., 2003). One of the reasons behind this is because academics have began to realize that the mathematical methods, in isolation, can not sufficiently capture and explain the entire scope of operations management (Swamidass, 1991). According to Dabbs (1982) "the notion of quality is essential to the nature of things. On the other hand quantity is elementally an amount of something". For the purpose of this study two research methodologies will be employed to provide a reliable results. The first part of the project will be carried out using qualitative data collection. This includes the use of case studies and preforming interviews within the targeted companies to generate a guideline on implementation of postponement the companies that have decided to re-shore. One of the advantages that the qualitative method offers is the capability of generating complex textual descriptions about the subject of studies. This method best suits the situations in which intangible factors are under investigations. In addition to this, according to the literature, the study done by Yang et al., (2005) suggests that the empirical research, particularly case study approach, offers the greatest advantages when studying the implementation of postponement in industries. Due to the immaturity of the subject within the academic context and limited practical application of re-shoring in the industrial level, various case studies will be nominated. The selection of the case studies will be done from smaller number of industries. Once the case studies are identified, they will be contacted to schedule interviews accordingly.

After that the validation of the results obtained will be the next. This will be determined using quantitative survey that can gather larger amount of data in order to validate the outcomes from the qualitative data collection. This is performed once the data are collected using in-depth interviews. After conducting face-to-face interviews with the company managers, framework on implementation of postponement strategy in re-shored companies in the UK will be obtained. However one of the limitations with regards to the case studies is the lack of generalizability of the findings. Hence in order to address such limitation, the results obtained from the interviews will be then validated using surveys. This will be in terms of a framework that can be adopted by the companies in order to improve their production and align them with the new generation of technologies such as big data and cloud manufacturing. Survey will be mainly sent to the SME's as well as large companies in automotive sector

Conclusion

Over the past few years manufacturing industry has witnessed a considerable revolution in the way that this industry operate. One of the most recent production strategies used in western countries such as Germany, France and UK is re-shoring strategy. Re-shoring is currently receiving significant attention by the media as well as academic environment. This is due to the urgent requirement to meet the customer specifications and survive in a dynamic business environment. As a result of this a new generation of technologies and business models are being developed to substitute the previously offshored manufacturing activities. In this study the different types of re-shoring and the reasons behind this strategy are investigated. Consequently the supply chain related issues are identified. Since re-shoring involves repatriating the manufacturing activities to the home country, the companies are required to develop a new supply chain configuration using local suppliers. This provides the platform to implement production strategies such as postponement. Hence in this research, the linkage and applicability of postponement in re-shoring is studied. This also allows the companies to align themselves with the new generation of technologies, the seven mega-trends introduced by Tata Consultancy Service, such as personalization and customization.

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Re-shoring & Offshoring trends: Managing Engineering Multinationals - A comparison of offshoring and outsourcing strategies in UK and German multinational corporations.

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Abstract

UK and German headquartered engineering multinational corporations (MNCs) are compared with a focus on their outsourcing and offshoring initiatives. A novel conceptual framework is developed that uses differing varieties of capitalism (VoC) to compare and contrast a series of criteria. Underlying theory is taken from the resource based view (RBV) of the firm and global production networks (GPNs). The findings from a comparative case study were that in the UK, lower labour costs and reorganising the value chain were key reasons to outsource and offshore. The UK business was less risk adverse and seemed more flexible and agile in its sourcing policies. The German organisation was less inclined to outsource preferring to retain control of a wholly owned offshore business unit. A further difference was that management in Germany were reluctant to progress radical initiatives with the works council. There was little evidence of re-shoring.

Keywords: offshore, outsource, varieties of capitalism

1. Introduction

Offshoring and outsourcing represent on-going and accelerating (at least until recently) trends in the restructuring of firms and has become a major part of (although not an exclusive driver) the globalisation trend. Offshoring can be defined as the performance of tasks in a different country to that where the firm's headquarters is located; while outsourcing may be regarded as the performance of tasks under some contractual arrangement by an unrelated third party (Harms, Lorz and Urban, 2009). Mergers and acquisition have a high risk of failure (Mitchell, 2004) and in recent years organisations have therefore sought alternative means of non-organic growth such as partnerships, joint ventures and alliances (Financial Times, 2011). While the initial justification to offshore is typically to arbitrage labour costs, the rapid growth in demand for outsourcing may lead to cost increases (Economist, 2011) and justification increasingly becomes a complex balance of proximity to markets, suppliers, ability to innovate and institutional factors such as governance and immigration policy (Pisano, 2009). Further, there is an increasing trend to outsource and offshore activities that demand higher levels of skills. According to Kirkegaard (2008) few topics in international economics have risen faster to the top of the political agenda, while also being so poorly understood and quantified as has outsourcing. Recent economic pressures have led governments in the United States and Europe to 'encourage' multinationals to return jobs and investment back to home markets (BCG cited in Economist 2011); beyond this, re-shoring has been motivated by poor or disappointing experiences in host countries, and declining economic conditions at home.

However, the institutional aspects of offshoring are under-explored and this research[1] aims to compare the practices, strategies and outcomes for case study firms from the UK and Germany, which are characterized by different capitalist models (Hall & Soskice, 2001; Lane, 1998). It is suggested that German firms for example, typically have stronger institutional links than typical UK competitors (Lane, 2008 cited in Morgan, Whitley and Moen). Furthermore, UK and German economies have different comparative advantages and industrial infrastructures, yet both countries also play host to a number of successful multinationals (MNC). The institutional context here can be understood as *both* the configuration of formal institutions (government, banks, trade unions and other firms) or as deeply embedded business practices and norms and 'ways of doing business'. This will shed light on how UK and German competing organisations differ in managing global expansion, and take advantage of the various resources and support available.

Following German reunification (1990) a period of austerity and strict wage control took place in Germany, and this helped to drive investment at home together with a strong export led economic revival. In 2012 German productivity was assessed to be 24 percentage points ahead of the UK in terms of output per hour (Financial Times, 2013). UK productivity was also 16 percentage points below the G7 average – the widest gap since 1994. A contested area is that the UK has been retaining employees rather than losing jobs to offshoring, while new work is created by UK outsourcing providers (see below). Throughout the 2008-9 recession, increased part-time working in the UK and even the hiring of new employees occurred at a time of minimal growth (Financial Times, ibid).

1.1 Aim

To examine the extent to which the offshoring and outsourcing strategies of UK and German based multinational corporations (MNCs) are embedded in the institutional contexts of their respective home countries. This gives rise to a number of sub – questions:

1. What are the differences between UK and German based MNCs in the geographical, functional and temporal patterns of outsourcing and offshoring?

2. How far do mechanisms such as ownership, control, coordination and the degree of autonomy differ between the UK and Germany?

3. How is this reflected in divergent international divisions of labour regarding the employment of indigenous or ex-pat managers from the home country?

4. To what extent do preferences for cultural proximity affect location choices?

5. What is the influence of trade unions in the process of outsourcing and offshoring and how is this reflected in the structuring of the firms' labour markets?

6. What evidence is there of a reversal in policy – re-shoring and why may it be occurring?

[1] This is part of a broader PhD Research study looking at two comparative UK and German case studies – airlines and engineering companies. The engineering case only is referred to here.

2. Literature review

The purpose of the first contextual stage of the literature review is to review the varying definitions, challenges with measurement, recent trends, background issues to, and the debate around outsourcing and offshoring. This will help in understanding the motivation for offshoring and outsourcing. Firstly, some definitions because the two terms outsourcing and offshoring are sometimes confused and deployed in very different scenarios. This will provide a context for the changes that have been taking place at the level of a firm in response to globlalisation and competition.

Offshoring means that work is moved outside the home country and therefore has geographical connotations, usually to a country which can perform the work at lower cost, or perhaps has special skills; although there might also be a business case for offshoring around new market entry and moving operations closer to the country of destination.

Outsourcing currently implies that an organisation decides to move selected activities from in-house (inside the organisation) to a third party or external supplier through a formal contract arrangement. The supplier may or may not be in the same country of origin as the organisation undertaking the outsourcing. The reasons for doing this may be multiple, but the usual starting point is to reduce costs, often labour and associated overhead charges. In so doing, the instigating organisation can be said to be reorganising its value chain and moving either core or support activities to the responsibility of another organisation.

Measurement difficulties often arise from problems associated with the identification beforehand and the allocation of costs and/or poor recording of government statistics. Offshoring work in particular may also be outsourced to a third party or indeed undertaken through a wholly owned subsidiary business (adapted from Contractor, 2010). Questions continue to be raised about the value of multinational expansion (Contractor, 2012).

A German perspective on the drivers and antecedents of manufacturing offshoring and re-shoring reviewed large data sets (Kinkel & Maloca 2009). Some 20 per cent of the organisations subsequently reverse their plan and re-shore within 4 years. This is mainly due to a lack of flexibility and poor quality. A deeper study of 39 German manufacturing companies confirmed a lack of attention to success criteria and competitive advantage. A UK study of offshore production in the years 2008-2009 (Liebl, 2010), found 14 per cent to have re-shored. This estimate for the UK has recently been updated by the Government's Manufacturing Advisory Service to 16 per cent (FT, 2013a). Reasons cited included: quality, shipping costs, difficulties in training, reduced flexibility, international payments, higher than expected quality assurance; or costs that were simply not accounted for in the offshoring move.

Three different but interrelated strands of theory have also been explored. From the fields of:

1. Operations, geography, economics and strategy, (Coe, N.M. et al, 2004) the concept of ***Global Production Networks (GPN).***
2. Business and economics, (Barney, J., 1991) the ***Resource Based View (RBV)***; and finally from
3. Geography and economics, (Hall, P. and Soskice, D, 2001) the concept of differing ***Varieties of Capitalism (VoC)***

The intention is to synthesise these differing approaches together with an understanding of offshoring to answer the research questions and to explore differences in how German and UK multinationals operate in specific business sectors, and manage offshoring / outsourcing processes in particular. This will also help in developing a conceptual framework – explored further under 3.1.1.

The lack of research on the interdependencies of geography and control is underplayed considering that firms operating in international markets face these decisions simultaneously (Dunning, 1988) and so whilst addressed in part by researchers of GPNs, the field is contested. Making these decisions independent of each other leads to short term, tactical sub-goal optimization. The strategic integration of these decisions can result in significant firm-level performance improvements (Banker et al., 1984). Most of the offshoring literature takes control decisions as a given. Similarly, the mainstream literature on outsourcing usually fails to explore the location decision.

Understanding the cost-benefit of offshoring and outsourcing is informed by RBV theory and concepts. This goes beyond the simple assumption of labour cost arbitrage towards the complexities of disaggregating home based processes and deciding what exactly to move offshore and where to locate it. Behaviour, whether rational or not, can be explored between buyers, suppliers and third parties in negotiating contracts and rents. If this can be combined with a better understanding of how to ensure that economic goals are embedded into social structures and the subsequent impact on behaviour then we have a compelling approach.

There are obvious limitations in clustering nation states, nevertheless broad comparisons seem possible. VoC can provide fascinating insights to the role of governments and institutions in juggling support and resources from the public to the private sector (and vice versa) also the extent to which institutions or the market influence prices and positioning. The real issue is the extent to which this benefits longer term growth and prosperity for firms and their shareholders. Whether coordinated versus liberal, production versus finance dominated, or corporatist versus pluralist private enterprise, most writers on VoC agree on distinct differences between UK and German systems of capitalism. The significant distinction is how German or UK MNCs then coordinate policy and whether they take their lead from the market or influential institutions to coordinate stakeholders. Further understanding of inter-firm linkages, power and competition is provided by the study of GPNs. The role of the lead firm is considered crucial in managing the impact of institutional policy on resource allocation decisions. Once offshore processes are sufficiently embedded that they add value back to the lead firm, further complex decisions are often required on (re)positioning (typically expensive) R&D and innovation resources, along with suppliers and customer markets. There seem to be several issues that are underplayed by existing literature.

> Firstly, institutional aspects of differing workplace environments and management groups largely responsible for decision making and policy setting of outsourcing and offshoring activity. If we consider the lead firm in a GPN, then there is an attractive argument that sustainable competitive advantage depends upon the firm's ability to manage the institutional context of its resource decisions (Oliver, 1997). Hence combining the resource based view with institutional perspectives from organisational theory overcomes some of the criticism of VoC (Granovetter, 1992) and seems compelling in practice. Institutional theory assumes that individuals are motivated to respond to external pressures. A criticism of GPN research (Hess and Wai-chung Yeung, 2006) is that empirical studies have a preference for qualitative interviews

with actors rather than empirical research data on the mechanisms and processes of GPNs. The 'cultural clash' that arose from European post socialist transformation over the past 17 years has attracted the attention of business partners from across the CEE. The body of organisational knowledge based on traditional, stable western market economies needs rethinking for sometimes unstable and ambiguous post-socialist environments (Soulsby and Clark, 2007). State Owned Enterprises (SOE's) tend to have functional hierarchies designed to have instructions and targets handed down through the various levels.

Secondly, a hotly contested area includes groups of labour and the impact of offshoring on employment levels. It has been suggested that improvements in technology (that link tasks across distance and borders) lead to domestic job losses through offshoring but also create jobs from cost savings associated with enhanced trade. Employment takes time to adjust to improvements in offshoring technology (Kohler& Wrona, 2010. So whilst there may well be contested arguments for and against offshoring with disputes on the pros and cons there is also a level of misreporting which confuses the facts. This is interesting to note as data reported tends to focus on jobs lost through offshoring misrepresenting the true effect; reconciling jobs lost and new jobs created (elsewhere) is extremely difficult. Gorg (2011) proposed four policy implications regarding employment: that offshoring leads to higher job turnover in the short run. Low skilled workers suffer, higher skilled may benefit but no evidence of overall increased employment in the long run; and finally, globalisation leads to structural changes in advanced economies from manufacturing to service sectors.

Thirdly, the dynamic and contradictory nature of relationships associated with re-shoring. The underlying reasons could be a mixture of changes in policy, costs, customer requirements, and market and / or business strategic plans. Either when poor decisions are taken at an early stage, or when institutional pressures change so work may be returned (or re-shored) to the home country. We need to better understand when re-shoring is simply the consequence of an over enthusiastic initial response to the competition, a response to a radical change in the cost and business model or the more recent political and institutional pressure in the 'national interest'.

3. Data & methodology

A mixed methods approach to a case study methodology is adopted with competitive comparisons drawn across the engineering sector for both UK and German headquartered MNCs. Seven semi-structured interviews with senior executives in Germany, UK, India and Czech Republic were undertaken. Initial research questions were refined and additional data requested. Further interviews were undertaken with supplementary visits to host and supplier locations, and data was triangulated by checking responses with four other major MNCs each with substantial China offshore operations (Appendix 4 Table 6). Interviews were with senior executives. Because the case studies inevitably comprise different sections of a business rather than the organisation as a whole the 'unit of measure' remains important in making comparisons and drawing wider implications. The methodology can be summarized as:

Table 1. Selected Combination of Approaches (author adapted from Saunders et al)

CRITERIA	SELECTION
Philosophy	**Pragmatism –** combining positivism and interpretivism
Approach	A combination of **deductive and inductive**
Strategy	**Multiple case studies** that are paired by sector with multinational corporations MNCs who are significant market players. To support the case studies some additional secondary data and / or research of archive material will be required to triangulate the findings.
Choice	**Mixed methods**
Time horizon	**Cross sectional** with some historical perspective to current time
Techniques & Procedure	**Semi structured interviews**, recorded transcripts, analysis using a mixture of quantitative and qualitative techniques, supplemented with additional secondary data collection.

3.1 Developing the Conceptual Framework

It has been suggested that a firm's decisions might evolve from initial cost saving through the outsourcing of support activities as a first stage of disaggregating the value chain and then process improvement and further leveraging of labour cost savings through offshoring. Finally, if the economic circumstances in the home market change then politicians might in some manner influence MNCs to reverse their policy and restore work back into the home market – re-shoring or similar (McKinsey, 2012). While this appears logical at a generic level, it may be rather too simplistic, especially at the level of a firm.

3.1.1 Proposed theoretical conceptual framework

A taxonomy for the relationships between LMEs and CMEs and their predicted approach to outsourcing and offshoring activity is shown below in Table 2. The first column distils the key questions that have been identified towards outsourcing and offshoring. Column 3 lists what are considered to be key dimensions to be explored through the research and subsequent analysis. Columns 4 and 5 represent hypotheses of anticipated responses if the companies conform to the stereotypical national LME model for the UK and CME for Germany.

It is intended that this conceptual framework and taxonomy will help to explore differences in the rationale, success and lessons between the UK and Germany for the engineering sector. The variables or dimensions chosen include the choice of location for outsourcing and / or offshoring which is essentially the reason or motivation that the company has for making the change, the control and coordination mechanisms in place, the levels of involvement and participation and finally, an ability to cope with changes in circumstances. The UK and Germany are compared using differing concepts of varieties of capital. The assumptions set out below and summarized in Table 2 are drawn from the literature (Lane, 1998; Lane and Probert, 2009; Whitley, 1997) in some cases reflecting a view that LMEs and CMEs are polar extremes, in other cases that over time there is some convergence and middle ground.

Taking each in turn, it is predicted that the motivation for outsourcing and offshoring will differ in that an LME will focus on short term cost cutting, budget control and shareholder interests. Initially, arbitrage of lower wages will be an inducement. If offshore they might also have a preference for English language speaking countries and traditional trading zones.

On the other hand CMEs whilst also regarding low cost as a 'given' will focus on medium and longer term benefits in quality and performance and therefore a reluctance to outsource losing control and potentially intellectual property, if they offshore preferring central or European locations with a cultural or language similarity. This makes assumptions, such as all companies in a particular country will to at least some extent mirror and practice some of the characteristics associated with that classification of VoC. Also, the model can be regarded as rather static when in reality countries, sectors, markets and individual company approaches are dynamic and adapt to differing economic situations. So for countries such as Poland, Hungary or the Czech Republic the VoC positioning may be regarded by some as having shifted from a 'Transitional' positioning to a 'Pluralist Private Enterprise' (LME) or even to a 'Mixed' central position.

Thus there is a link to the second dimension of ownership and related aspects such as control and coordination and degrees of autonomy. This draws on GPN theory to the extent that policy and practice become embedded in the supply chain, the network and the territory. Also LMEs might be expected to be heavily focused upon the needs of the shareholder, strict cost and budget control as referred to above and an arm's length approach towards strategy – do what you have to do to meet budget and hence a high level of autonomy, as long as the local business stays within budget. A CME however, might be expected to be more likely to follow a multiple stakeholder model with a balanced approach to the differing needs of customers, suppliers, employees as well as shareholders; this is often referred to as market driven and customer focused. A CME might also be predicted to retain tight control over strategy, policy setting and resource allocation, and hence comparatively low levels of local autonomy, with a more hierarchical structure and somewhat slow to change with major decisions to be ratified centrally. A CME is therefore more constrained by institutional factors that influence managerial decisions such as 'what to offshore or outsource' and 'where to'?

The RBV and associated work on dynamic capabilities helps to inform us on how the lead company will manage core competences and resources. In deciding to transfer work from in-house and the home market are there than sufficient skilled resource to help the business transition work to either a third party or to an offshore subsidiary? With regard to managerial division of labour, LMEs might recruit local expertise with only a minimum of expatriate managers. Such individuals are often attracted to the lifestyle and financial benefits and choose to stay longer term. In terms of cultural proximity they are more likely to be flexible and opportunistic with a low(er) level of concern other than an ability to speak and work in English where possible. CMEs may be predicted to invest more initially in setting up offshore operations with a comparatively high level of expatriate managers to transfer processes, set-up operations and organize training of a local workforce. Gradually they might transfer expertise to local management. Compared with LMEs a higher level of priority would be given to cultural proximity in terms of behaviour's and language.

One of the key institutional factors to be explored is the role played by the trade unions and works council; and the inter-relationships with employees and management. For LMEs it is assumed that the influence is low or even non-existent, management will 'push the boundaries' once a decision has been taken within legal requirements and may be confrontational to enforce the decisions considered essential for the future of the business, especially at a time of poor economic prospects. CMEs on the other hand, are assumed to be more consultative, actively avoiding confrontation.

Finally, we address evidence of a reversal in policy and returning work to the home country. For LMEs this might be influenced by political pressure or economic incentives. With CMEs we are assuming that this may be more likely to be a result of a change in market focus and /or strategy or a loss of intellectual property rights.

So, a theoretical projection is shown below in Table 2 presenting a series of hypothesis on what we might expect from a MNC headquartered in either the UK (LME) or Germany (CME). The case study will provide a 'test' for the conceptual framework of the theory both in use and practice covering products such as pumps, valves and seals for the offshore oil and gas industry together with software / hardware for the automotive components market. See Table 3 (engineering) for summaries also further analysis in with preliminary findings (to date) in Table 4.

Table 2 Conceptual Framework - Theoretical Projection

Question	Approach	Dimensions	Liberal market economy UK (LME)	Coordinated market economy GERMANY (CME)
What are the differences in the geographical, functional and temporal patterns of outsourcing and offshoring?	Outsource	Motivation	• Cost cutting and employee reduction • English speaking countries • Traditional trading zones	• Quality and performance, cost control is 'a given'. • Central / Eastern Europe preferred
How far do mechanisms such as ownership, control, coordination and the degree of autonomy differ?		Ownership	• Shareholder driven	• Multiple stakeholder
		Control & Coordination	• Arm's length on strategy. Strict cost and budget control	• Tight HQ control of strategy, policy and resources
		Degree of autonomy	• High – if meet financial targets then local control	• Low • Hierarchical structure • Can be slow to respond to change
How is this reflected in divergent international divisions of labour regarding the employment of indigenous or ex-pat managers?	Offshore or	Managerial Division of labour	• Low initial use of ex-pat managers who then stay on	• High initial use of ex-pat managers for set-up and training. Subsequently local management
To what extent do preferences for cultural proximity affect location?	outsourced offshore	Cultural Proximity	• Low, flexible, opportunistic	• High – language, behaviour

What is the influence of trade unions in the process of outsourcing and offshoring and how is this reflected in the structuring of the firms' labour markets?	or reverse offshore (Re-shore)	Relationship with employees / Trade Unions	• None, limited to legal requirements • Push the limits • Can be confrontational to enforce desired changes	• Consult widely • Actively avoid confrontation • Opportunistic – use growth to create additional jobs elsewhere
What evidence is there, and why of a reversal in policy – re-shoring?		Change of policy	• Loss of initial cost-benefit. • Political pressure or economic incentives	• Loss of intellectual property • Change in market focus or strategy

4. Empirical analysis

4.1 Discussion of the manufacturing and engineering sector. (Let us call the UK engineering company 'C' and the German engineering company 'D').

With seven semi-structured interviews (see Table 5) at 'C' and 'D', in some depth and detail it is possible to draw some general points regarding answers and relevance to the research questions. This engineering case study does provide insights on differences in approach with respect to competences, technology transfer around the world and the development of key alliances; as postulated by Lynn and Salzman (2009).

There are similarities in focus for both UK and German companies – to initially cut costs, keep prices down and then to improve efficiencies, processes and customers service. The method of delivery however, is different. The UK company 'C' takes a long term view but with short term deliberate steps towards partnership and then integration and acquisition, utilizing outsourcing and offshoring where appropriate. The German company 'D' however, prefers to retain centralised control by establishing a subsidiary business offshore from the outset, with no or little consideration of outsourcing. There is also little evidence of synergies across the German group. Both 'C' and 'D' companies have grown and employment has been largely protected, although the United States division of 'C' has reversed a policy to move work to Mexico back into the US. It would also seem that complex work offshored to India by 'D' has subsequently had to be re-worked in Germany.

For summary of findings and comparison with conceptual framework (see Appendix Table 3). The key challenges for the engineering businesses include:

1. On-going cost control, especially in the UK company which is Shareholder driven.
2. Customers ask for, and expect lower prices and local supply.
3. Competitor pressure within the market and industry sector.
4. Preferred tendency with 'C' to try a joint venture and then acquisition, integrate and restructure to reap rewards.
5. More control if it is a wholly owned subsidiary of 'D', can then avoid issues of IP with a third party.

5. Conclusions

It is well known that Germany has managed its economy in such a way that it has been less exposed to the economic pressures suffered by much of the rest of Europe. To some extent this has allowed management to move operations offshore but not outsource, gain the benefit of lower costs (some 10 per cent at least) without losing jobs at home. However, as costs increase at a faster rate in many overseas markets the search for productivity benefits and efficiency gains continues. The basic components of a 'coordinated market economy' seem to prevail with evidence of institutional coordination, long term planning but also central control and an aversion to risk. The UK Company was quicker to outsource, favoured short term cost savings but was also more flexible and agile, taking risks with trade unions and suppliers and customers to seemingly favour shareholders. In many respects this is consistent with the 'liberal market economy' capitalist model. In both cases the choice of location was often different, as was the approach to delegation and autonomy suggesting differing views on governance. The underlying theoretical constructs of varieties of capitalism, the resource based view and global production networks were each found to be of value. See Tables 3 & 4

(Research Questions 1 & 2). German Companies use expatriate managers for the short term but then mostly rely on local skills. UK companies use local staff from the outset. German companies also place more emphasis on language, near shoring and cultural empathy (Research Questions 3 & 4). UK companies may have a tendency to be adversarial with trade unions, forcing job reductions when considered to be essential whereas German companies were cooperative and averse to conflict where possible (Research question 5). Only isolated cases of re-shoring were evident from the two companies (Research question 6).

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Appendices

Appendix 1 Engineering Case Summary

Table 3 UK and German Engineering compared

Question	Approach	Dimensions	Liberal market economy (LME) UK	Coordinated market economy (CME) GERMANY
What are the differences in the geographical, functional and temporal patterns of outsourcing and offshoring?	Outsource	Motivation	UK, Czech Republic, China Less keen on India. Catering, administrative and revenue accounting, engineering, maintenance, repair and overhaul. Cost	India, Vietnam, Czech Republic – 'lead' global roles in Asia, Europe and North / South America. Embedded software applications, IT systems, accounting, call centres. In Czech Republic – the development of new automotive platforms; R&D, Engineering and Manufacturing. Local expertise and cost.
How far do mechanisms such as ownership, control, coordination and the degree of autonomy differ?		Ownership	Offshore through Joint Venture then wholly owned acquisition. Financial control via HQ, but freedom to run business locally.	Now wholly owned, offshore subsidiaries, budget control and OEM contact through HQ.
		Control & Coordination	Global operations via HQ	HQ with OEM, divisional control and global coordination from HQ

		Degree of autonomy	Relatively high	Relatively high in terms of design and delivery. Close budget and resource planning and monitoring from HQ.
How is this reflected in divergent international divisions of labour regarding the employment of indigenous or ex-pat managers?	Offshore or outsourced offshore or reverse offshore (Re-shore)	Managerial Division of labour	Kept to a minimum	Ex-pat initially as senior manager. Replaced with local after 5 years, maybe 5 ex pats out of 10,000 local employees. In Czech Republic initial training of engineers in Germany then on-site over 2 years. Ex pats may stay.
To what extent do preferences for cultural proximity affect location?		Cultural Proximity	Significant preferences through experience	Less important – although with the Czech Republic there are advantages of proximity, similar markets, some ease of language and cultural affinity.
What is the influence of trade unions in the process of outsourcing and offshoring and how is this reflected in the structuring of the firms' labour markets?		Relationship with employees / Trade Unions	Redundancies where required	Avoid conflict, timed to coincide with growth to avoid job losses in Germany. Few issues in Czech republic – weak union but also free labour market and plant growth offering security.
What evidence is there, and why, of a reversal in policy – re-shoring?		Change of policy	Mexico back to the US	Stories of complex work being returned from India to Germany for rework.

Appendix 2 Table 4: Interpretation of initial pilot research questions – headline comparison of Engineering sector case studies: approaches to offshoring and outsourcing. Source: author

RESEARCH QUESTION	FINDING
To what extent are German and UK multinational companies displaying different varieties of capitalism and how does that effect decisions and strategies related to the deployment of outsourcing and offshoring?	To some extent the differences here are subtle rather than significant. There is some evidence of Corporatist / coordinated behaviour in Germany and liberal by the UK company. A huge reluctance to outsource anything other than Travel services by the German organisation is apparent. The similarities are common – both employ high quality engineers and other specialists, both are keen to cut cost and improve efficiencies. Both have grown and are successful.
What is distinctive about the governance of German and UK multinational firms?	The role of MNC in transferring technology is a key FDI flow Both cases meet the usual criteria high R&D, large share of professional and technical workers, complex technical products, high levels of differentiation. Advantages come from ownership, location and internalization (Dunning, 1988); and democratic countries such as India and Czech Republic tend to attract more FDI with lower country risk, debt risk. What is unusual with the German case here is that there is little communication across the group only between headquarters and a specific subsidiary.
How is the above reflected in idiosyncratic patterns of outsourcing and offshoring at both a national and sector level?	The UK case suggests that they will deploy whatever approach is most applicable, especially for short term gain; also that the German organisation will avoid outsourcing in favour of controlled offshoring.
Which functions or processes are moved offshore, where to and why?	Not so much functions as products and then the entire business support system that is required for those products in both Germany and the UK.
In what ways does the embeddedness of firms influence the motives, control and strategy of the parent multinational company?	In Germany long term development of FDI has resulted in considerable growth and recognition that maturity is now close to optimum in India leading to the establishment of a second, smaller clone in Vietnam. The UK company have restructured and developed a global strategy, a current priority of which is to coordinate common IT platforms across the sites.

To what extent are outsourcing and offshoring policies reversible, and what is the experience in Germany and the UK?	None observed here within Europe but the US division of the UK Engineering company has reversed a policy to move work from the US to Mexico.

Appendix 3
Table 5: List of semi structured face to face and telephone Interviews
(typically 1hour each)

UK COMPANY 'C'	**GERMAN COMPANY 'D'**
Slough Dec 2011 VP Operations	Stuttgart Oct 2011 VP Engineering
Slough Dec 2011 Director Group Operations	India Dec 2011 Company President
	Prague Jan 2013 Director
Follow up Nov 2012	Follow up Nov 2012

Appendix 4. Comparative summary from 'other' interviews. Thematic / Content Analysis

To help triangulate the findings and as a check of the data and their interpretation it was decided to undertake some further interviews, again in the engineering sectors but not the aforementioned case study organisations. Each of the chosen organisations were multinational corporations, of mixed origin and HQ base (see Table 6 below), and each with a significant presence in China. The interviews of approximately one hour duration each took place in Shanghai during two trips Spring 2013 and Spring 2014. The interviewees were senior managers mainly working in procurement and supply chain roles.

Key messages from the 'other' multinationals interviewed in China (see Table 6 below):

- A number of these organisations have separate profit centres / business units with headquarters located in different countries. This is a result of mergers, acquisition and subsequent restructuring. In terms of designating a variety of capitalism (Hall & Soskice, 2001) the original country is shown first and assumed to be dominant.
- Transport and Engineering sectors are reasonably homogeneous. Sub sectors e.g. Transport: automotive, rail, aerospace display similar characteristics as does Engineering: Power, automation, building products.
- Wholly owned subsidiaries preferred, outsourcing currently largely limited to components but expected to move towards sub-assemblies that offer more added value, consolidation of complex supply chain, higher skills and different capabilities needed.
- P & L responsibility retained at HQ but sourcing concentrated regionally.
- Consideration given to reduce manufacture in Asia when US local market labour rates are attractive. More consideration given now of total costs including material and transport.
- Management teams very international, mixed nationalities with wide experience.
- Culture, language and geography are considered to be important. (Table 6 Thematic Analysis from semi structured interviews).

Table 6 Comparison with four sector compatible MNCs – each with a major China offshore base.

	ENGINEERING			
INDUSTRY SECTOR	**Company E (automotive)**	**Company F 2 Divisions (aerospace & rail)**	**Company G (robotics)**	**Company H (building products)**
HQ LOCATION	Swedish / US	French Canadian /German	Swedish / Swiss	US
VARIETY OF CAPITALISM MODEL (Hall & Soskice)	**CME / LME**	**LME/CME**	**CME/CME**	**LME**
NO. EMPLOYEES & COUNTRIES	56,000 employees in 29 countries	Aerospace: 76,000 employees in 26 countries Rail: 34,900 in 59 countries	147,000 employees in 100 countries	8,500 employees in 8 countries
CURRENT OUTSOURCING / OFFSHORING INITIATIVE	**Outsource:** Training of procurement staff	**Offshore:** Use China as a wholly owned low cost base from which to export (especially for Rail). Good local supplier network in China.	**Offshore:** Factories are all wholly owned subsidiaries. There is international (becoming global) sourcing of parts / components. Now a gradual shift towards sub-assemblies (added value). Will require adaptation of supply chain and a change in supplier skills / capability.	**Outsource:** 100% of Laminate flooring <10% of total cost is labour so policy will now be reviewed with lower costs in the US (70% of total sales). **Offshore:** Ceiling products are manufactured local to market.
CULTURAL PROXIMITY	Follow the customer – wherever market need	International management team. Culture, language and geography are regarded as important. Railway is conservative and expects suppliers to work in local	Shanghai serves Asia market, Sweden the European and US the Americas. Fit with supplier regarded as key. Very international	China provided a low cost offshore site primarily for flooring products and also access to SE Asia markets

		language.	management teams.	
TRADE UNIONS	Work closely with local management	Discussions take place but no current issues.	Trust is important especially between Europe and China.	'Employee Club' reviews work conditions, pay and vacation period. Employee turnover is high, workers return to their rural village and do not then come back to work. Government Policy under review on rural versus urban entitlement to health, education and property.
DRIVER		Low cost, some innovation. Little added vale at moment but expected to increase.	Strategically identifying changes in core and secondary supplier parts. More added value in a shift to sub-assemblies	
COST / BENEFIT		Supplier Enumeration Approval Process. Total cost of ownership is reviewed and there are comprehensive QA systems. 30% average saving.	European Committee reviews local cost versus India / China benchmarks. Review total cost of product.	
TRENDS / CHANGES			Supply chain becoming more important and consolidated. Different suppliers with different skills and capabilities required for the future.	
CONTROL / LOCAL DEVOLVEMENT		Orders placed on a regional basis – in-line with legal entity. Close relationships with local suppliers.		Product managers in US have P&L responsibility. Close communication and regular travel to meetings.

LABOUR COSTS				Senior management costs in US, Europe and China are similar. Blue collar worker costs in China are cheaper 2500 to 3500 Yen per month.
RE-SHORING	A number of instances. Process and control and quality the main reason.	No evidence yet in rail. Prevalent in automotive. No political pressure to date.		

Configuring Large Scale Electrical Energy Supply Chains to Improve Sustainability: Implications for Supply Chain Design

2014 Cambridge International Manufacturing Symposium
Cambridge, England
11-12 September 2014

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Keywords: energy supply chains, statistical model, economic analysis, advanced technologies

ABSTRACT

Electrical energy supply chains have evolved slowly. Much of recent development has been in advancements toward large scale development of alternative energy production technologies to improve supply-side capacity and reduce pollution from existing production technologies (Mateus & Oliveira, 2009; Snyder & Kaiser, 2009; Türkay & Telli, 2011). Less improvement has occurred in demand-side management (DSM) of electrical energy systems, where electrical generators work to smooth demand and reduce generation capacity needs necessary to manage high peak demands (Aalami, Moghaddam, & Yousefi, 2010). In this study we demonstrate field results from an advancement in demand-side information technology coupled with advanced customer segmentation and customer analytics which allows producers and distributors to reduce peak electricity demand and lower total system costs while maintaining consumer satisfaction and reducing total plant emissions.

INTRODUCTION

Electrical energy supply chains have evolved slowly. Much of recent development has been in advancements toward large scale development of alternative energy production technologies to improve supply-side capacity and reduce pollution from existing production technologies (Mateus & Oliveira, 2009; Snyder & Kaiser, 2009; Türkay & Telli, 2011). Less improvement has occurred in demand-side management (DSM) of electrical energy systems, where electrical generators work to smooth demand and reduce generation capacity needs necessary to manage high peak demands (Aalami et al., 2010). In this study we demonstrate field results from an advancement in demand-side information technology coupled with advanced customer segmentation and customer analytics which allows producers and distributors to reduce peak electricity demand and lower total system costs while maintaining consumer satisfaction and reducing total plant emissions.

With the cooperation of the largest electrical energy producer in the U.S. and one of their key distributors, the results of our study demonstrate a reduction of up to five to ten percent of peak electricity demand. This approach reduces peak capacity requirements by sophisticated demand shifting to reduce use of high cost peak generators and coal-fired plants, with the added benefit of reducing expensive reserve capacity and postponing construction of new plants for many years. Surprisingly, this advancement uses current information technology and allows implementation in electrical energy production and distribution within a few months.

THE PROBLEM

One of the major limitation of electrical energy is the difficulty and cost of large scale storing of electricity (Gorria, Jimeno, Laresgoiti, Lezaun, & Ruiz, 2013). Our technology partner in this study, Carina Technologies in Huntsville Alabama, USA, solves this limitation by using a patented technological innovation to make it more profitable to "store" electricity than to not store it, using electric water heaters as a large scale battery system. Electric water heaters represent one of the few efficient ways to store large amounts of energy within existing infrastructure. By managing energy storage with electric water heaters, significant residential electric demand can be shifted away from expensive peak times to lower demand periods that utilize lower cost electricity generation technologies. This not only provides dramatic cost savings opportunities for utilities and power generators, but also reduces total energy consumption.

Our study uses a very large dataset that provided unprecedented detail for analysis and the development of effective control strategies. Our analysis shows that substantial energy shift and savings were achieved, and we discuss various statistical techniques we have applied as well as economic analysis of the costs and benefits of the program. The results indicate various opportunities for optimizing implementation strategies for a very large system of such devices, while providing lower energy consumption and cost savings across the energy supply chain. The success of the pilot program has led to a larger scale deployment within the largest electrical energy system in the U.S.

Capacity Management

Daily demand for electrical power generation varies by time of day, day of week, and by season of the year. The fundamental problem in supplying electrical energy to support this demand is that peak capacity is very expensive per kWh (kilowatt hour), and using prior technologies for large scale storing of electrical energy as “inventory” or “safety stock” to be provided during peak periods is even more expensive.

Capacity buffers for electricity generation to meet peak demand are mandated by U.S. regulations, as *reserve capacity*. That is, to avoid blackouts and brownouts during peak demand, reserve capacity is necessary to meet peak demands and provide power system reliability (U.S. EIA, 2013). Reserve capacity must be planned and built years in advance due to time lags in capacity investment and reliance on long term forecasts for changes in demand growth. Pressure to reduce greenhouse gasses, common to generators utilizing coal fired plants, adds an additional challenge to maintain lower long term cost per kWh while reducing reliance on one of the lowest cost technologies for electricity generation. And variation in power generation from newer technologies such as wind, solar and biomass increase the variance of production, inducing higher reserve capacity requirements. Reserve capacity becomes very expensive for electricity generators, so they also focus on demand management to smooth demand where possible to reduce variation in daily demand, which in turn reduces reserve requirements. This reduces the need for current *and* future operational and reserve capacity for gas turbine generators for peak electrical energy generation.

Demand Side Management

The lowest cost technology for large scale U.S. electrical energy production is nuclear power (U.S. EIA, 2012). The drawback to nuclear power is that takes the most time to ramp energy generation up and down, so it is used to provide energy for the most stable portion of electrical energy demand. Coal is the second least expensive form of electrical power generation[1], and advanced gas turbine electrical energy production in the most expensive. It is the quickest to turn on and off and has lower capital costs relative to nuclear and coal-fired plants, but has very high operating costs due to its fuel source. Gas turbine generators may only operate for an hour a day, for example, at peak times. See Figure 1 for a notional depiction.

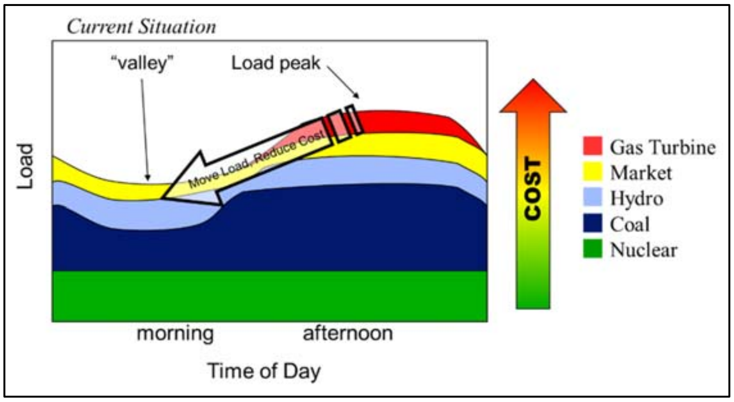

Figure 1 - Store energy during "valley", showing an afternoon peak

Electrical generators and distributors have used DSM programs for many years. DSM programs encourage consumers to participate in the planning, implanting and monitoring of energy reduction activities to modify electrical usage (U.S. EIA, 2002).

DSM programs for industrial users often focus on differential pricing and energy efficient equipment, but industrial producers need electrical energy during daytime peak hours and subsequently pay higher peak load pricing due to necessity. DSM programs for end consumers often consist of asynchronous devices that manage usage at the end consumer level for a period of time during excessive peak demand periods.

A NEW METHOD FOR STORING ENERGY

The idea of storing energy focuses on having electrical energy stored prior to the beginning of peak periods so that this peak demand can be partially supplied by the stored energy. The depleted energy storage can then be replenished during non-peak periods ("valley") where the energy can be produced at much lower cost (Figure 1). But how can we store energy at such a massive scale?

Current battery technology that can store a megawatt or more of energy are cost prohibitive for commercial scale electricity generation. Hydroelectric power can utilize water pumped up a hill at night, at low cost, and run back down the hill during peak demand periods to generate power. This is currently used, but takes large quantities of water and storage space so it is not used on a large scale. Large scale capacitors are too unwieldy using current technology. Heating, ventilation, and air conditioning (HVAC) systems provide some storage capacity, but poor insulating qualities of many buildings is a major problem.

[1] While hydroelectric is the lowest *regional* cost per kWh where available, it is generated at a much lower scale of total power generation and its use is highly restricted to suitable geographical locations.

One viable solution using current technology is using two-stage water heaters[2] as equivalent to a battery system, storing energy during low cost periods and providing use during peak times. Water heaters provide a remarkably clean, safe, efficient and cost effective solution. Water heaters are a clean technology, where stored power is generated over night by nuclear, wind, or cleaner coal (utilizing centralized scrubbing). They are efficient because water heaters are very well insulated, and therefore store thermal energy effectively. They are cost effective, and no new generation technology is needed since many homes can use existing water heaters. Water heaters are also safe, where water temperature in the U.S., for example, can be heated up to 135°F, regarded as safe for most customers. And consumer comfort, measured as hot water available when consumers want to use it, can be managed effectively while reducing temperatures to a comfortable minimum temperature of 110°F when not needed in the near future.

Water Heater Programs

Several generators and/or utilities have used water heater cycling for decades to take advantage of these storage properties under their DSM programs. Implementation has generally been with "dumb" units that simply shut down the water heater during peak hours. There is little or no communication with these DSM units. Often utilities don't even know if the units are working or not. These asynchronous DSM devices accept control signals from a central controlled unit, or are programmed to shut the water heater down during specific times.

They are not "smart" devices that can communicate back to a central information hub to offer anything more than crude DSM control during peak demand. They are unable to signal when the device stops working, so energy savings from the remaining operational devices are difficult to reliably estimate. And they may inconvenience end customers due to lack of electrical power to devices with DSM controllers when consumers may want to use them.

Recently our industrial technology partner, Carina Technologies in Huntsville, Alabama, USA, developed patented hardware and software to allow synchronous control and feedback to aid in improving the effectiveness of DSM management plans. Their technology allows for continuous monitoring, feedback, and control of devices that consume electrical energy during peak demand periods.

Our UAH team worked with Carina Technologies to determine if their technology was technically and economically feasible for deployment with large scale electrical energy producers, in a pilot program in conjunction with Tennessee Valley Authority (TVA), Bristol Tennessee Essential Services (BTES, a TVA distributor), and the Electric Power Research Institute (EPRI).

The goal in this study was to evaluate whether it was possible to install these "smart" devices onto an existing electrical grid, capture data on actively managed DSM units while also managing a control group for comparison purposes, then evaluate the results for technical and economic performance.

[2] On demand water heaters cannot store energy, thus are not a viable solution.

Smart Water Heater Control

Carina Technologies developed the Water heater Information System for Energy (WISE)(Figure 2), which is comprised of electronic hardware and software to control the unit, a real time cellular or internet connection for communication between the unit and a centralized controller, and a centralized control system that manages both the test units and control units during the study (Figure 3).

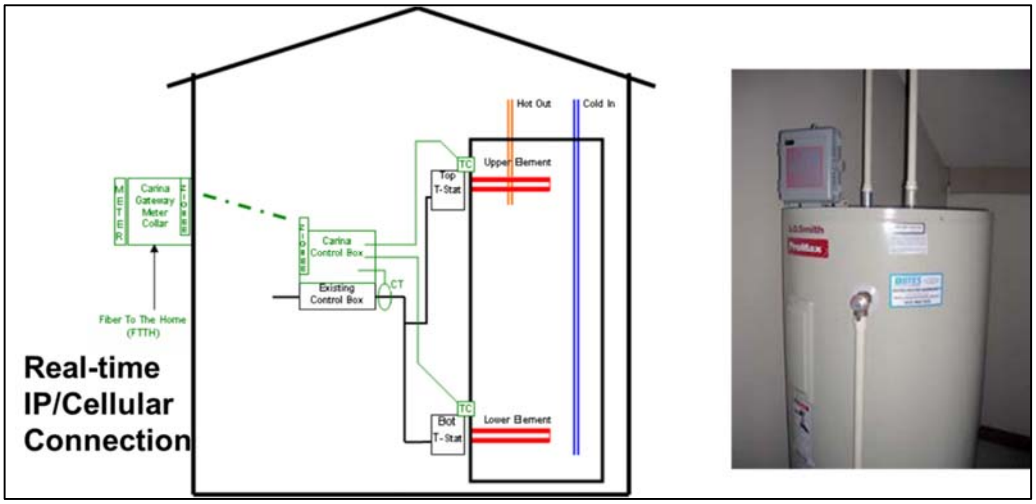

Figure 2 - Water heater Information System for Energy "WISE"

Pre-Pilot Program

The WISE technology, demonstrated in a pilot program in Bristol, TN, proceeded in two phases. The first phase in 2009 was a small pre-pilot program, where a team from UAH performed advanced mathematical analysis of demographics related to water heater usage and potential to store and shift loads. From these preliminary data, the team was able to demonstrate an effective segmentation process and demonstrate effective predictive capability using the algorithms and customer segmentation scheme.

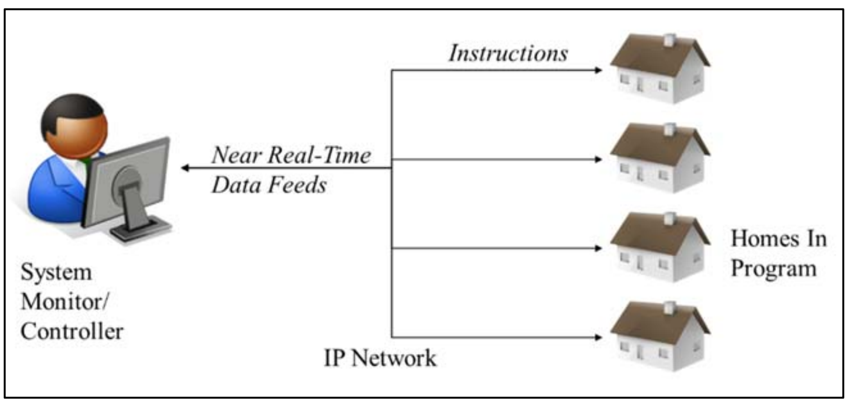

Figure 3 - Control system for the WISE units

Demographic Analysis - Statistical Method

Six demographic groups were segmented from the data, as shown in Table 1.Average demand

Index	Type
0	Child, 0 – 5
1	Child, 6 – 13
2	Teen, 14 – 21
3	Non-working adult, 22 – 65
4	Working adult, 22 – 65
5	Non-working senior, 66+
6	Work senior, 66+

Table 1 - Individual types for segmentation

patterns by individual type are shown in Figure 4.These individual types, in various combinations, can represent different types of households. The analysis included energy consumption by type of household, both in quantity (kWh) and by time of day (time step), and then the individual household demands were cumulated by daily time segments to forecast total demand by time period (every 15 minutes). To do this the UAH team considered each household as a linear combination of its individual residents. Demand in house *j* (d_j) for each time period is considered a linear superposition of these residents' demands, where each household is comprised of *n* residents of type *k* in house *j* ($n_{k,j}$) and $\hat{d}_k$ is the estimated coefficient of demand for household type *k* (Equation 1).

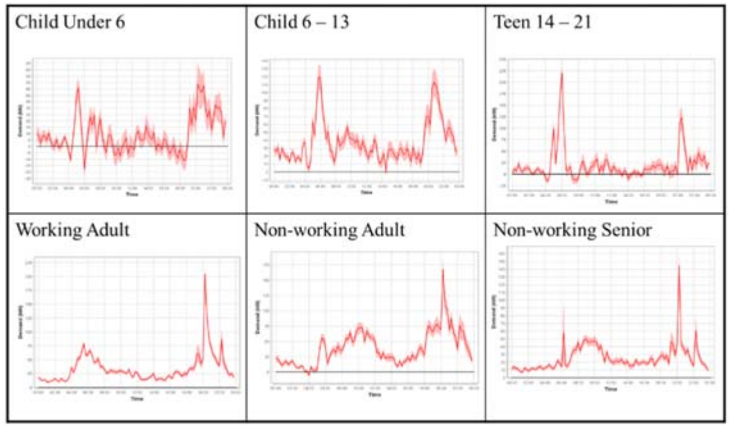

Figure 4 - Aggregate demand patters by type of individual

$$d_j \approx n_{0,j}\hat{d}_0 + n_{1,j}\hat{d}_1 + n_{2,j}\hat{d}_2 + n_{3,j}\hat{d}_3 + n_{4,j}\hat{d}_4 + n_{5,j}\hat{d}_5 + n_{6,j}\hat{d}_6$$

Equation 1 – Demand at a single time step

Over the *M* households in the study, we can find the total estimated demand that is best in the least-squares sense. Thus total predicted demand in each daily time step is $\sum_{j=1}^{M} d_j$.

The benefit of this approach is that it allows predicting how households comprised of differing sets of individuals provides an approach for strategic implementation and treatment schedules, as shown in the next section.

Pilot Program

The second phase in 2011 was a full pilot program analysis using approximately 900 homes in Bristol, Tennessee (TN), during the winter months. This study generated a large volume of production-quality data[3], which was highly suitable for data analysis. During the analysis, the UAH team confirmed successful load shifting through statistical analysis, and identified trends in data that may suggest successful implementation strategies. Results from testing load shifts and differences in energy consumption in the pilot group were compared to the null hypothesis, that for the pilot test a household's energy consumption using DSM treatment was not statistically different from the control group households that received no treatment to their energy use patterns.

RESULTS

From understanding how individual electrical demands vary by individual type, and how there are different household segments that are comprised of various combinations of adults and children, the UAH team used the statistical model developed in the pre-pilot study to predict usage by various households.

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[3] Our dataset contains more than seven million records.

Validation of Predicted Behavior by Household

Figure 5 illustrates that for three household types a) three working adults, b) two working adults and one teen child, and c) two working adults and two children aged six to thirteen years, the predicted results fit actual results very well. These three household segments consumed hot water with different patterns during the day, but the patterns were predictable.

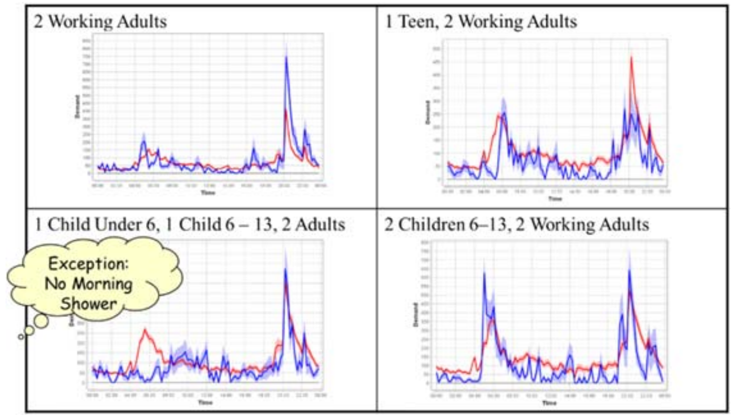

Figure 5 - Actual demand (red) and predicted demand (blue)

Times for showers, baths, laundry, and using an electric dishwasher, for example, were reliably predicted by household segment. For the fourth household segment, two adults, with one child under six and one child between six and thirteen, the statistical model fit fairly well in the evening but the model did not sufficiently predict water used for morning showers within this household segment. Two other household segments comprised of non-working adults and non-working seniors were identified but their patterns by individual exhibited so much variation that customer satisfaction of individual households could not be ensured. To maintain the criterion of high customer satisfaction they were excluded from the test. This approach can be used for any number of household types.

With a reasonably fit to the household segments, the next step in the pilot study was to randomly segregate a test group from a control group. All of the household electric water heaters were fitted with WISE controllers to monitor temperature of the upper and lower stages of water in the water heater as well as energy consumption throughout the study. Half of the residences in the pilot study received the demand shift treatment, the other half of the WISE units simply recorded results (time, energy used) without treatment.

Shifting Demand

The treatment group received control instructions to allow heated water in the water heater to be used as needed according to normal consumption patterns in the mornings, but delayed the reheating of the water beyond 110^0F until the peak demand period had passed, typically around 11:00 am during the study. The control group received no DSM control instructions, and reheating water initiated immediately until it reached it normal operating temperature of 135^0F. One of the constraints in the study is that customer satisfaction was primary, so the control strategies were designed to ensure that enough how water was available for each of the customer segments when they wanted it. This approached differed from traditional DSM program that simply stopped delivery electricity to the hot water heater during peak demand periods.

The analysis included a test of model predictions against actual demand, as well as treatment and non-treatment water reheating patterns until after the peak demand period. Customer satisfaction was also measured in the study. Once the peak demand period was over, the treatment units turned on and recharged the hot water to 135^0F.

Load Shift Analysis

The study was comprise of a full winter run of Bristol pilot data. All of the units provided data back to the control servers, recording time of day , control unit status (active or control unit) whether the control strategy was active at the time, energy consumption, and temperature of the upper and lower stages of the water heaters. Three minimum temperature strategies were evaluated during the peak shift periods, as shown in Figure 6. The analysis tool used is a custom Java package written at UAH that could be easily integrated into real-time monitoring and analysis engines.

In **Error! Reference source not found.** the control units that received no treatment are denoted by the red line, and units under the *shift the load* treatment strategy are shown in blue. From these results the UAH team has extremely high confidence that the shift the load strategy was effective from a demand management perspective. This strategy was effect at all three temperature settings, but most effective for the lowest temperature setting. The treatment program for the treatment period from 5 am to 11 am produced a load shift of more than 92% of the normal peak morning load. But what are those large spikes at 11:00 am?

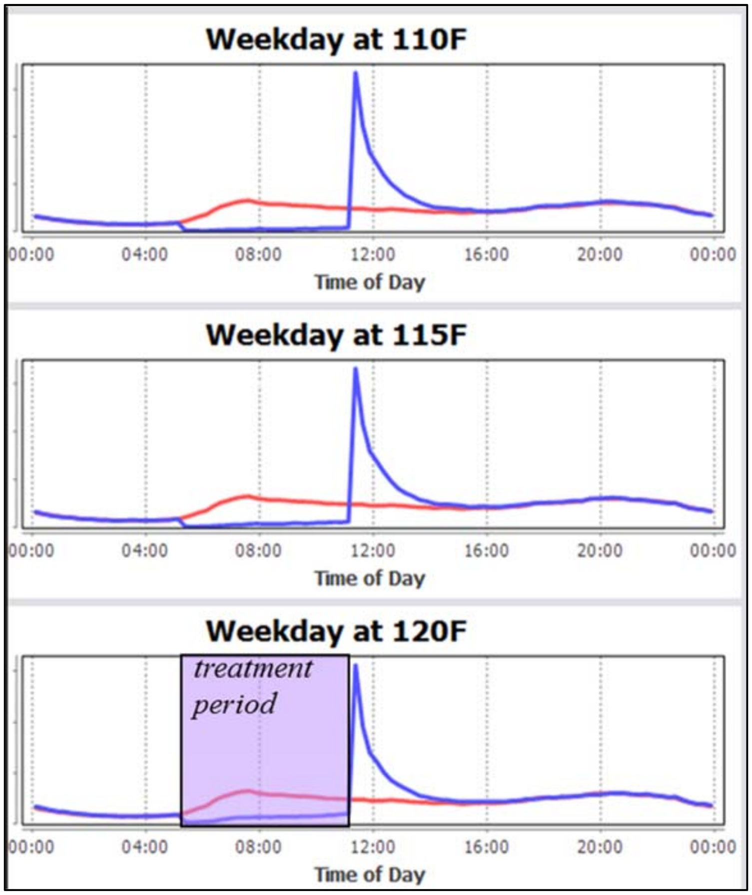

Figure 6 - Load shift during peak demand. Control units in red, treatment units in blue

Feathering

In **Error! Reference source not found.** a problem is clearly evident. We're trying to *remove* the peak, but have created a new, severe rebound peak when heaters cycle back on all at once at the end of the treatment period. No effort was made at this stage to stagger, or "feather", the recharging of the hot water heaters to avoid a spike in demand once the peak period was over. The pilot study was intended to demonstrate how well the statistical model predicted behavior and how well peak energy could be *shifted* until some arbitrary time in the future. This is the first step in a two part strategy called *shift and store*.

In order to store this energy demand until needed to recharge the hot water heaters, algorithm development is needed to optimally "feather" the recharging of the hot water heaters to accomplish two goals while still maintaining high customer satisfaction: a) move as much of this energy demand to the lowest cost time periods as possible, and b) stagger the recharging times so the units don't all cycle on at the same time and create a new, higher peak.

Optimally Storing Demand

The next step after this study is to determine exactly how to long to defer, or *store*, this energy consumption to recharge hot water heaters at lowest cost to the generators and distributors while continuing to ensure high customer satisfaction. Designing optimal control strategies to determine how long to store energy consumption in live large scale energy systems is a very complex process and is left to future work.

ECONOMIC BENEFITS

Highest and Lowest Performers

What is this worth to be able to shift demand to a lower cost time period? Aggregate results were shown above, but segmenting the results into which customers provided the most shift and which provide the least in demonstrated in Figure 7.

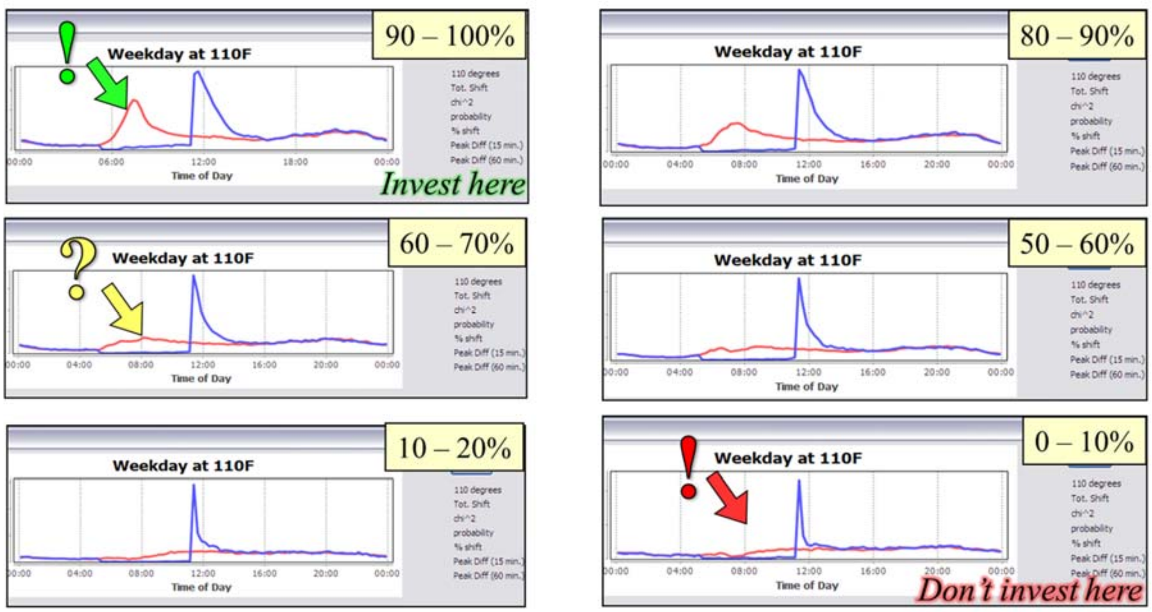

Figure 7 - Identification of "load shift performer" segments

From Figure 9, households where peak demand shift during the treatment period was above 90% clearly represents the top candidates for load shifting to lower cost energy generation periods. Households with peak electrical load shifts below 20% are not likely to be good candidates for investing in advanced DSM technologies such as WISE, but a detailed economic analysis is needs to confirm these suspicions and to determine the load shift threshold by which load shifts are no longer economically feasible.

Average Peak Shift

In this pilot study the UAH team was able to demonstrate an average load shift of more than 92% for peak morning load for residential customer's electrical power. This translates to a five to ten percent[4] reduction in *total* peak load for TVA in the mornings. But what is this worth in an economic analysis? The results are explained in the next section.

Economic Analysis

The UAH team began a sophisticated analysis of benefits to the electric power generator (TVA), distributors and customers. What appeared to be a relatively straightforward economic analysis quickly became complex. The economics for a power generator were not the same as for a distributor or an end customer. Following is an overview of the variables that are important to the economic analysis, but no attempt is made to provide a comprehensive explanation.

Parameters

Power generators charge for both power and energy. *Energy* charge is a fee for how much electricity was consumed in total for a billing period. The also charge for peak power, as *demand* charges , where power is defined as energy consumption for a short time period, such as kWh per second. Demand charges are typically set for distributors and the maximum power consumed, in this case, within the highest peak hour period in a given month. This demand charges is then applied times the total number of kWh in the month. It's similar to a capacity-available charge. There are differing demand charges for summer and winter in this study.

Energy charges very by season and off season. There are six energy price rates in this study, used across the twelve months in the annual analysis. There are parameters for independent corroborations of energy shift achieved in summer and winter, parameters for kWh consumption during winter and summer periods, and parameters for reduction in total energy consumption per day and cost reductions due to load shifting to lower cost time periods that utilize lower unit cost energy generation.

There are also parameters for costs of the hardware, installation, software maintenance, communication hardware and access charges, and potential incentives from the power generator to induce distributors to move from ineffective DSM programs to this more effective program. These revenues and costs often utilizing step functions, where prices change rapidly between times of day, day of week and month in the year. These induce nonlinearities in the economic analysis that make it difficult to model using straight forward equations.

Net Result

The analysis used discounted cash flow analysis for ten and fifteen year net present value (NPV) for blocks of 10,000 homes inducted into the program at a time. The NPV for 10,000 residences was in the millions of dollars, suggesting a strongly positive return.

The analysis was also run for up-front full cost versus monthly fees to amortize the investment by distributors over time. These results are conservative for two important reasons. First, the cost difference between peak demand prices and off peak prices, which comprise the marginal savings for demand and energy charges, does not take into account that future advanced algorithms to optimally feather the recharging of the hot water heaters

[4] Actual number disguised.

will bring the marginal cost of recharging down to the variable cost of coal or nuclear energy production. In the case of nuclear energy production with demand shifted to after peak evening hours, the marginal cost per kWh approaches zero. Often there is more electrical energy produced by nuclear plants during the wee hours of the morning than is demanded, so excess electricity is run into the ground. Now this electricity can be *sold* for almost pure profit rather that wasted.

Second, moving five to ten percent of morning peak load generation on an ongoing basis to a lower cost time period in the day reduces the total operational capacity necessary for the system and lowers the total reserve capacity requirements for the system. Total operational capacity is the capacity necessary to provide full power even during peak demand periods. Reserve capacity is the equivalent to safety capacity, which is a function of the variance in demand and capacity generation technologies installed and online at any given time by the power generator. As noted above, the technologies for providing peak capacity utilize gas fired advanced turbines, which have a very high variable cost. Reducing peak demand by five to ten percent eliminates the need for many operational gas turbines, as well as for planned construction over the next several years to provide sufficient operational and reserve capacity for future growth in electoral energy demands. These reduced or deferred capital costs can range into the hundreds of millions of dollars.

Current Status

This work validated the technical and economic feasibility of an advanced DSM program utilizing the WISE technology. As a result of this study, TVA and one of its key distributors are now deploying the WISE technology to 30,000 homes. TVA has also supported other distributors deploying this technology across their grids to begin the long process of upgrading previously installed but outdated DSM technologies.

Limitations of the Study

One of the limitations of this study is the location of the pilot study. Bristol, TN, is representative of a certain region of the U.S., but it does not represent the many differing regions across the country. Differences in regional energy production costs and technologies, demand patterns, and market pricing patterns will significantly affect the technical and economic results of such a study. While the authors expect equally positive results in other regions, for the final results the analyses must be conducted.

In addition, the economic analysis ignored emerging competing technologies in the study. There are few viable alternatives today to synchronous DSM technology such as the WISE system, but recent advances in other energy technologies, such as advanced electric car batteries and smart charging stations, open future opportunities for other electricity storage systems. For example, in the future it should be feasible to use electric cars as energy storage devices that can feed electric energy into a smart grid energy during peak demand periods and be recharged during lower demand time periods. Whether this will occur within a few years or more than a decade is speculation at this point. Such systems are not necessarily competitors to the WISE system, but rather complimentary systems – all of which are competitors to future installation of peaking generators by producers.

Yet the installation of advanced generation and storage technologies induces other complexities that do not currently exist in current power generation systems. Increases in future use of wind and solar power induce amplified daily variations in power generation and reliability, measured in this case as percent of continuous availability during planned power generation periods. Adding the complexities of how to manage the feathering of load shifts complicates an already complex control process for managing multiple interconnected power generation and distributions grids. This future work is outlines in the next section.

Future Work

Future work following from this study includes advanced modeling techniques used to generate optimal or near optimal algorithms for balancing the costs of shifting demand with the impact of inducing new peaks back into the electrical energy grid during off-peak times. This includes implementation of different priority strategies, and must account for the intricacies of the power generation plants and ranges of technologies and operating practices that are operational at any given point in time.

For example, phasing out older coal fired plants, adding wind or solar power generation capacity to electrical power grids, refueling schedules of nuclear plants, growth in electrical energy demands, and the increasing market share of electric cars add uncertainties that must be accommodated in the development of algorithms designed to optimally feather demand shifts back into electricity generation schedules. Methods developed in this future work have wide-ranging applicability to other storage strategies and sources, such as electric cars and local solar production.

CONCLUSION

Water heaters provide one of the few inexpensive, effective and reliable ways to store energy on electrical power grids. Asynchronous direct load control switches have had modest success due to crude DSM management strategies. Switches with real-time two way communication, such as WISE, offer a massive leap forward. They provide constant monitoring, re-programmability on a weekly, daily, or hourly basis. They provide central control that offers generators substantial opportunities for handling demand variation issues (simple “shift and store”).

Advanced DSM technologies offer substantial system-wide cost savings and capital equipment avoidance or deferral while maintaining high customer satisfaction levels. The bottom line is that it is possible to leverage the IT technology boom using existing technology to solve energy problems *now*, rather than waiting on the hoped-for boom in energy generation tech.

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Supply chain adaptation through phases of product innovation life cycles

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Abstract

An innovative product's life cycle affects dynamics of supply chains significantly, necessitating a defined SCM strategy for each life cycle phase. Furthermore, the adaption of the supply chain strategy and structure must be executed quickly, as innovation life cycle phases are often short and phase transitions can occur abruptly. In order to ensure supply chain effectiveness throughout an innovation's life cycle, efficient performance measurement is of high importance. The findings of this paper support metric-driven models for SCM, and the application of a prioritisation of the SCOR performance attributes. During each phase of the product innovation life cycle, the performance attributes need to prioritised to a different extent in response to changing market environments. The framework provides guidance for setting up boundaries for KPI systems by relating supply chain strategies to SCOR performance attributes.

Keywords:

Supply Chain Management, Product Life Cycle, Supply Chain Adaptation, Innovations

1. Introduction

An ever-ongoing environment of technological innovation has precipitated the rapid advancement of innovative products, which require a different set of strategies for SCM (Parlings, Klingebiel, 2012). To respond to the challenge of identifying the right supply chain strategy for innovations, existing models and recommendations have been presented such as Fisher's (1997) Supply Chain Strategy Matrix and Lee's (2002) Uncertainty Matrix. Moreover, Fenn and Raskino (2008) examine the development of innovation life cycles on Gartner's "hype cycle," a model that has not yet been fully validated in the space of current SCM strategies.

From a supply chain perspective a high uncertainty especially with regard to market acceptance and therefore sales volume is distinctive for an innovation. Previous methods for managing uncertainties have focused on maximizing flexibility within the boundaries of the current system (Kuhn et al., 2011). Yet, current research has shown that the supply chain has to be enabled to change its strategic direction and its structure in accord with dynamic technological changes. The supply chain shall be changeable in structure, processes, and resources (Bertsch and Nyhuis, 2011; Klingebiel et al., 2012). Thus, Parlings and Klingebiel (2012) have presented a framework for managing innovation product cycle cycles in SCM by aligning supply chains with the degree of maturity.

This contribution builds upon the framework by Parlings and Klingebiel and seeks to respond to open issues with regard to the supply chain strategies linked to the innovation life cycle phases. It further expands the framework by connecting these strategies to supply chain performance attributes that provide guidance to practitioners in implementing the strategies. To achieve these goals, this paper is organized as follows: A review of the current state-of-the-art is presented in chapter 2. The findings presented in chapter 3 include a discussion of the supply chain strategies through innovation life. Furthermore, a prioritisation of SCOR performance attributes is carried out in order to support the corresponding strategy. Best practices are linked to each life cycle phase based on the prioritisation of performance metrics. Chapter 4 summarises the findings and gives an outlook to further research.

2. State of the Art

The following section describes the basics and recent development in the related research topics. The first section examines the state of the art in strategic SCM in regard to product innovation life cycles. Furthermore, general approaches for adapting the supply chain strategy are discussed. Section 2.2 discusses research in KPI-driven frameworks in SCM, and is followed by an intermediate conclusion and an assessment of current research.

2.1. Adaption of Supply Chain Strategy and Product Innovation Life Cycles

Supply Chain Design (SCD) integrates long-term and strategic decisions on the configuration, planning, and management of supply chains (Chopra and Meindl, 2010; Simchi-Levi et al., 2004). 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 superior SCD task is to *identify the appropriate supply chain strategy* (Parlings et al., 2013a). In today's dynamic business environment supply chain strategies need frequent reconfiguration which in turn requires a dynamic strategy adaption methodology. Particularly, dealing with radical innovations is challenging for adapting the supply chain strategy as changes occur rapidly.

Innovative products are defined as a function of their novelty and commercial use, as the classification of a product hinges on its differentiation from existing products and its economic utilization (Hauschildt and Salomo, 2011). For describing the development of innovations over time and analysing the expected changes within the market, various life cycle models have been developed (Parlings and Klingebiel, 2012). The most common models include the Diffusion Process model, the Adoption Curve, the Performance S-Curve, the Maturity Curve, the Standard Life Cycle model and Gartner's Hype Cycle (Nieto et al. 1998; Linden and Fenn, 2003; Rogers, 2003).

Attenuating supply chains to external forces such as market developments has been analysed in theory by authors such as Mason-Jones et al. (2000) and Christopher and Towill (2000). They have proposed that lean and responsive supply chains are best matched with practices that are risk adverse, agile or leagile. Some models, such as Fisher's (1997) Supply Chain Matrix, have used the novelty and commercial success of a product to provide short-term guidance about SCM, but fail to provide a coherent and long-term plan for SCM with innovative products. Moreover, Wang et al. (2004) and Vonderembse et al. (2006) have matched the principles of being lean, agile, or hybrid to discrepant product types and phases of the standard product life cycle. In a specific case, Aitken et al. (2003) have proposed a life cycle model based on a case study in the lighting industry. A supply structure is matched by the life cycle phase of the respective product.

A framework that integrates innovation life cycles, supply chain strategies and addresses main tasks to be accomplished in different life cycle phases has been presented by Parlings and Klingebiel (2012). By combining appropriate life cycle models, their work serves as a guideline for choosing the right supply chain strategy along early innovation life cycle phases. The phase division into the five phases technology trigger, inflated expectations, trough of disillusionment, slope of enlightenment and plateau of productivity is based on Gartner's

Hype Cycle (Fenn and Raskino, 2008). Characteristics from various life cycle models such as technological maturity and financial performance have been assigned. For each of the resulting supply chain phases, appropriate strategies und tasks have been defined (see Figure 1).

Hype Cycle Phases		Phase 1: Technology Trigger	Phase 2: Inflated Expectations	Phase 3: Trough of Disillusionmet	Phase 4: Slope of Enlightenment	Phase 5: Plateau of Productivity
Supply Chain Phases		Monitoring and Integration	Supply Chain Setup and Responsiveness	Consolidation and Adaptability	Scale-Up and Agility	Efficiency and Hybrid strategy
Supply Chain Characteristics	SCM Strategy	Monitoring and Awareness	Responsive Supply Chain	Adaptable Supply Chain	Agile Supply Chain	Hybrid, leagile Supply Chain
	SCM Tasks	Design Chain Integration, Risk identification	Resist the hype Highly reliable supplier base	Consolidation of supplier base, Cost-efficiency	Scale-up logistics and supplier capabilities	High-scale production Efficiency

Figure 1. Framework for mastering innovation from a supply chain perspective (Parlings and Klingebiel, 2012)

Measuring the effectiveness of the supply chain strategies in each life cycle phase by using appropriate KPI frameworks is crucial for successfully managing the supply chain throughout the innovation life cycle (Parlings and Klingebiel, 2013b). Therefore, the state of the art in KPI-driven SCM is elaborated in the following section.

2.2. KPI-driven Supply Chain Management

Modern advances in operations research hinge on the use of data and analytics to streamline the decision process. These methods are largely driven by the use of industry standard Key Performance Indicators (KPI). In the field of Supply Chain Management, a high variety of holistic performance metrics systems are proposed by research (e.g. Keller, 2010; Giese, 2012; Chopra and Meindl, 2013) as well as by practice-oriented organizations such as the well-established German industrial standard VDI 4400 (Cirullies 2011) or the SCOR metrics developed by the Supply Chain Council (Supply Chain Council, 2012). Given its widespread implementation in academics and business as well as special implementations in innovation research (e.g. Wang et al., 2004; Parlings et al., 2013b), SCOR has gained outstanding significance.

In SCOR, a set of hierarchical KPIs that can be compiled together into five key performance attributes (Agility, Responsiveness, Reliability, Asset Efficiency, and Cost) is defined (Supply Chain Council, 2012). Agility relates to the ability to respond to external influences, like changes in the marketplace, whereas responsiveness describes the ability to perform its tasks quickly. Reliability describes the rate at which tasks are performed as expected. Cost and asset efficiency refer to the ability of the supply chain to operate with low expenditures and with an efficient usage of fixed assets. These performance attributes serve to guide the strategy of a particular business. SCOR provides a set of indicators in three hierarchical levels for each performance attribute. Derived from the supply chain strategy target corridors need to be defined for each performance attribute. These serve as guidelines for individually defining acceptable boundaries for the underlying indicators (Parlings et al., 2013b). Alongside the indicator system, SCOR provides industrial guidelines by dividing industry-wide established supply chain concepts into emerging practices, best practices, standard practices and declining practices, which vary in levels of risk and effectiveness. Thus, SCOR offers a diagnostic, hierarchical framework for SCM, and recommends industry practices for process selection (SCC, 2012).

Liao et al. note that supply chains often suffer from a problem in data availability, and that their convoluted nature represents an intractable problem in that information often cannot be synthesized to an actionable level until after it would otherwise be obsolete (Liao et al., 2011). One possible means of subverting this information problem is to use a more general scale for guidance, such as a maturity model (McCormack et al., 2008). Within the development of a supply chain, there are three distinct stages that can thus be measured by changes in KPI, the initial growth stage, the secondary growth stage, and the tertiary stage of stability and continuing growth (Liao et al., 2011). These methodologies have converged into a framework presented by Parlings et al. (2013b), which presents a KPI framework for SCM with innovative product life cycles.

2.3. Intermediate Conclusion and Research Gap

As the investigation of previous research has shown, an innovative product's life cycle affect dynamics of supply chains significantly, necessitating a defined SCM strategy for each life cycle phase. The state of an innovative product can be ascertained through a number of well tested models like S-Curves and the Hype Cycle. The framework presented by Parlings and Klingebiel (2012) provides a good basis for aligning supply chain strategies. Nevertheless, the underlying strategies need to be discussed in more detail and guidelines for implementing and measuring best practices are missing. KPIs are an effective means to assess the validity of a supply chain. Parlings et al. (2013a) suggest utilising SCOR performance attributes and metrics for evaluating the effectiveness of supply chains throughout an innovation's life cycle. However, there is a research gap in determining what information should be weighted at a given stage of an innovative product's life cycle, and furthermore what SCOR performance attributes should be leveraged at such a stage. It is generally understood that during certain times, a supply chain must value its agility and cost effectiveness differently, but these methods have not yet been directly associated to innovative products (Ivanov and Sokolov, 2012).

In order to response to this research gap, the general guideline for determining phase transitions for aligning supply chain strategy with life cycle phases by Parlings et al. (2012, 2013b) needs to be dynamically linked to the best and emerging practices that have been established by SCOR. The unification of these systems will validate the previous definitions for supply chain strategy and present a cohesive strategy for innovative product life cycles. Based on the advanced definition of supply chain strategies throughout the innovation life cycle, SCOR performance metric need to be prioritised and best practices are exemplary assigned to the phases. Chapter 3 seeks to further develop the Parlings and Klingebiel framework by responding to the need for research discussed herein and following the suggested actions.

3. Advancement of the Supply Chain Innovation Framework

This section will complete the SCM strategies presented by Parlings and Klingebiel (2012) by integrating established practices with the defined stages of product development. Furthermore, an introductory model for the prioritisation of SCOR performance attributes is presented, which can be used to allow the supply chain effectiveness to be continuously assessed.

3.1. Methodological approach

Based on the previous work by the authors, this section combines supply chain strategies established in research and industry with the triggers of Gartner's hype cycle and aligns best practices with these stages. It is assumed that the product is a radical innovation that is new to the supply chain itself as well as the overall industry sector. It does significantly differ from previous products which leads to a high uncertainty in predicting the market development. The observation of the product starts at the very beginning of the life cycle when first prototypes attract market attention. Based on these characteristics it is assumed that small-scale production is being followed in the early life cycle phases until the product reaches the maturity stage which marks the end of the supply chain innovation framework.

Methodologically, a four-step approach has been followed. Each supply chain phase has first been analysed focusing on the most relevant characteristics. Secondly, the corresponding supply chain strategies and main tasks as originally introduced by Parlings and Klingebiel (2012) have been discussed, expanded and adapted, resp.

In the third step, the strategies have been connected to SCOR performance attributes in order to allow the supply chain to be continuously assessed by its effectiveness. This is in line with the SCOR understanding of performance attributes: "A performance attribute is a grouping of metrics used to express a strategy." (SCC 2012, p. i.4). After strategic directions had been identified for supply chain performance metrics referring to SCOR, best practices are assigned to each phase in step 4. Here, SCOR best practices have been integrated into the framework for innovative products.

3.2. Development of supply chain strategies through phases of innovation life cycle

In this section, the supply chain strategy framework for product innovations (see **Figure 1**) is discussed and further expanded. The 5-step approach presented in the previous section is being followed for analysing and expanding the framework phase by phase.

Phase 1: Technology Trigger

The technology trigger is the first stage of an innovative product's life cycle, and it is marked by the initial introduction of the product to the market and media. This stage is defined by a technological breakthrough that begins to attract the attention of the press, and begins to rise in hype as the media begins to explore the technology (Linden and Fenn, 2003). In the scope of the hype cycle, this is a period of significant turbulence and little progress, and is often financially unsuccessful for a company (Lu and Beamish, 2004). The previous framework for supply chain management with innovative products has defined this stage as a phase of monitoring and integration (Parlings and Klingebiel, 2012). Essential tasks within this framework include design chain integration and risk identification, and there is a broad goal of monitoring and awareness. Given negligible market adoption, the supply chain is in its embryonic stage, and the company itself is in emergence. The most pressing goal of this stage is to identify risks and opportunity in advance.

This understanding is also supported by Liao et al. who characterize the "initial stage" as being marked by the integration of the supply chain and the management of unknown risk factors to maintain a responsive supply chain (Liao et al., 2011). In the nomenclature of the framework presented by Parlings and Klingebiel (2012), this stage is met with strategies for an "aware" supply chain, which largely focus on monitoring design chain integration.

Given that the supply chain must react to uncertain demand and unknown supplier interactions, it follows that agility and responsiveness at this stage of the product life cycle is prioritised. In the initial stages of process development, responsiveness is especially critical, as there is a high potential for market change (Williams et al, 2013). Emerging products can potentially face demand beyond the manufacturing capabilities of the firm, which can lead to an overwhelming impact that affects the supply chain from manufacturer to supplier (Amini and Li, 2011). To prevent this, agility is emphasized, even potentially at the expense of asset efficiency and manufacturing reliability. Since it is of high importance to not disappoint first customers, reliability should be a high priority to companies. Liao et al. (2011) assert that the reliability of the supply chain is essential for both supply chain relations and market reputation. In this initial implementation, cost and asset efficiency are not of premium concern, as uncertain demand necessitates that responsiveness is much more critical (Christopher and Holweg, 2011). The relative prioritisation of SCOR performance metrics in this initial trigger phase of product innovations is summarized in

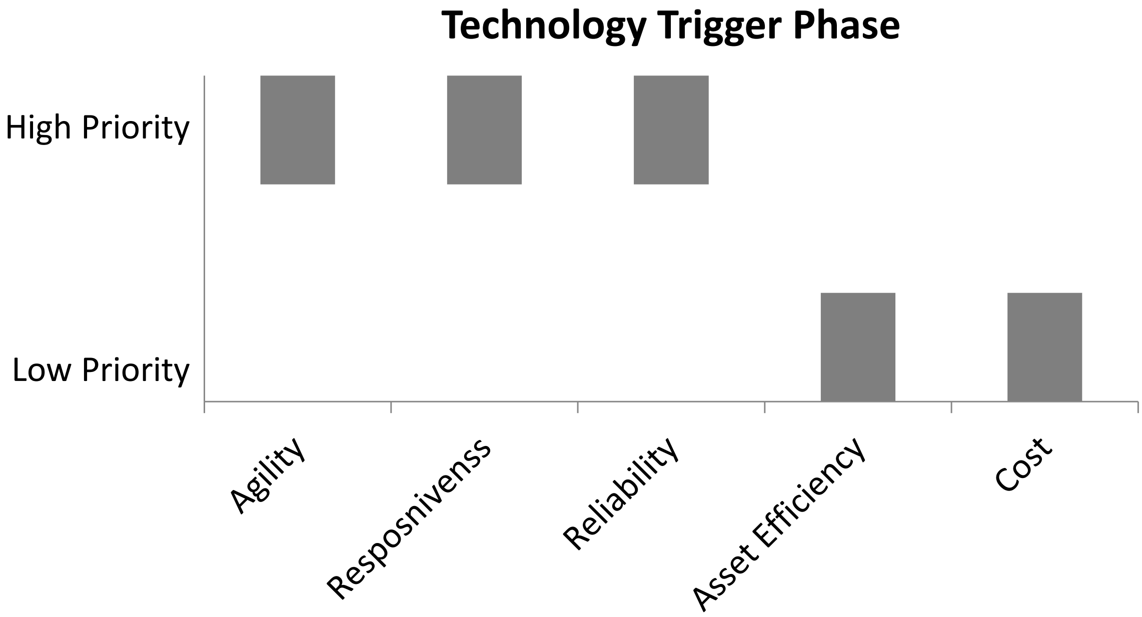

Figure **2**.

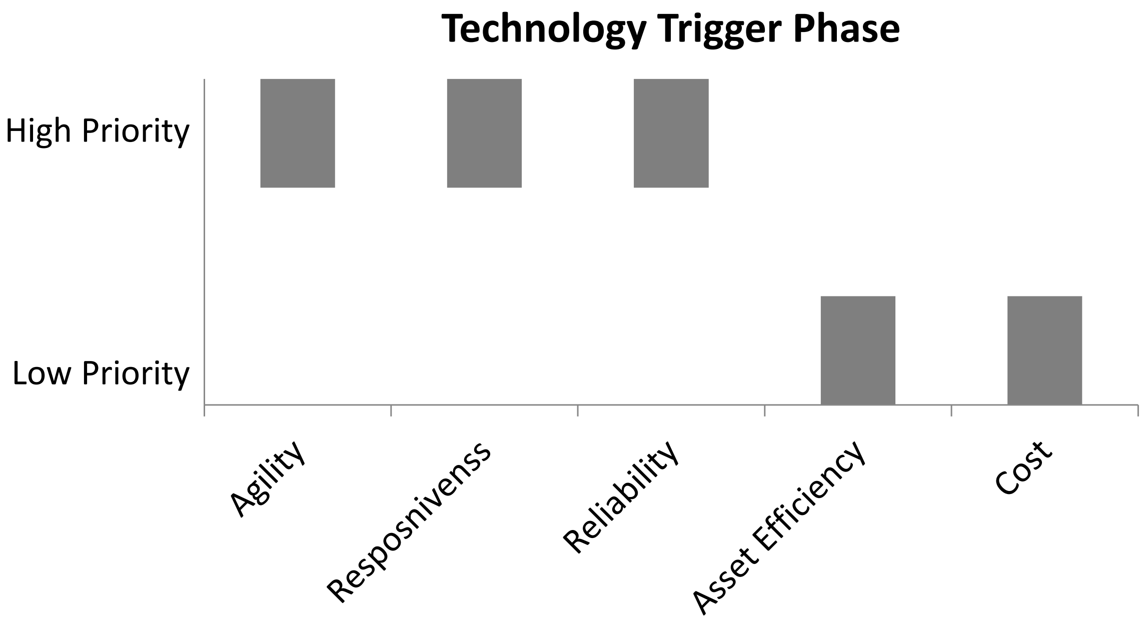

Figure 2. Prioritisation of SCOR performance metrics in the trigger phase

Regarding the initial production strategy, supply chains should begin with a MTO strategy when production quantities are small and market uncertainties are high at the beginning of a radical innovation's life cycle (Parlings and Klingebiel, 2012). This reduces the amount of uncertainty associated with sales forecasting, and is similarly defined as a best practice by SCOR (Parlings and Klingebiel, 2013b). With regard to sourcing decisions and supplier management, Wannenwetsch (2009) identifies target costing and the long-term supplier development as core tasks in the early product development stage.

Phase 2: Peak of Inflated Expectations

During the Peak of Inflated Expectations, the market penetration and hype level reaches the highest levels. This involves both an ascent and an eventual peak, which occurs somewhat ambiguously (Linden and Fenn, 2003). From a hype cycle view, the second phase is marked by enthusiastic media coverage and an increase in venture capitalists and vendors (O'Leary, 2008). The most important goal at this stage is not getting "swept up in the hype" and creating an unsustainable product delivery strategy. In this stage, the demand for a product is highly variable, and cannot be accurately forecasted, despite the efforts produced in the prior stage.

This is otherwise known as the emergence stage (Linden and Fenn, 2003). Thus, this stage is still, generally speaking, in the initial stages of growth for a product. The frameworks by Liao et al. (2011) and Parlings and Klingebiel (2012) isolate the establishment of a reliable supplier base as one of the most integral techniques of this stage of development. From a SCM perspective, this phase begins to establish the responsive supply chain, as the increase in number of suppliers, and the bettered relationships thereof, increases the reliability of the product and the ability for the supply chain to consistently carry the product from implementation to market (O'Leary 2008; Parlings and Klingebiel, 2012).

Supply chains in this stage are characterized by being responsive and have the tasks of diversifying themselves as a means of mitigating risk and forming a resilient form of supply. For this reason, they often adapt a strategy of establishing reliable and agile supplier bases and "resisting the hype", so as to mediate overextention (Liao et al., 2011; Parlings and Klingebiel, 2012). However, reliability is not of the highest importance at this stage of the life cycle, as customers during the hype peak might be willing to compromise reliability factors such as on-time delivery. Following the empirical findings on successful responsive supply chains presented by Roh et al. (2014) it is crucial to implement open-communication channels for real-time information sharing to ensure fast and valid information about market demands and demand patterns. Furthermore, the authors point out the importance of long-term partnerships with crucial suppliers and customers (Roh et al., 2014, p. 208). Cadden and Downes (2013) note that price efficiency is not paramount at this stage, and that it is more important to find suppliers that are reliable (and agile) than those that are cost efficient. Moreover, these methodologies are further supported by frameworks which leverage a mathematical formulation for supply chain networks under transient demand variations (Georgiadis et al., 2011). This model encompasses factors such as network complexity, manufacturing complexity, sourcing decisions and allocation decisions to create an aggregate decision model based on changes in demand. It suggests that safety stock is necessary in stages of high market volatility, which corroborates the prioritisation of responsiveness and agility (Georgidadis et al., 2011). When launching a new product, speed is often more important than cost (Amini and Li, 2011).

Concluding, with regard to SCOR performance attributes, this second stage of development continues to emphasize responsiveness in order to adapt to fluctuations in the market. Additionally, the need to establish a reliable reputation requires a responsive supply chain strategy. In relation to the priorities presented in phase 1, the responsive supply chain must place a much greater focus on reliability and asset efficiency, and must generally operate as a more efficient supply chain, which becomes easier as collaboration between firms increases with familiarity (Cao and Zhang, 2011). The relative prioritisation of SCOR performance metrics in this phase is summarized in

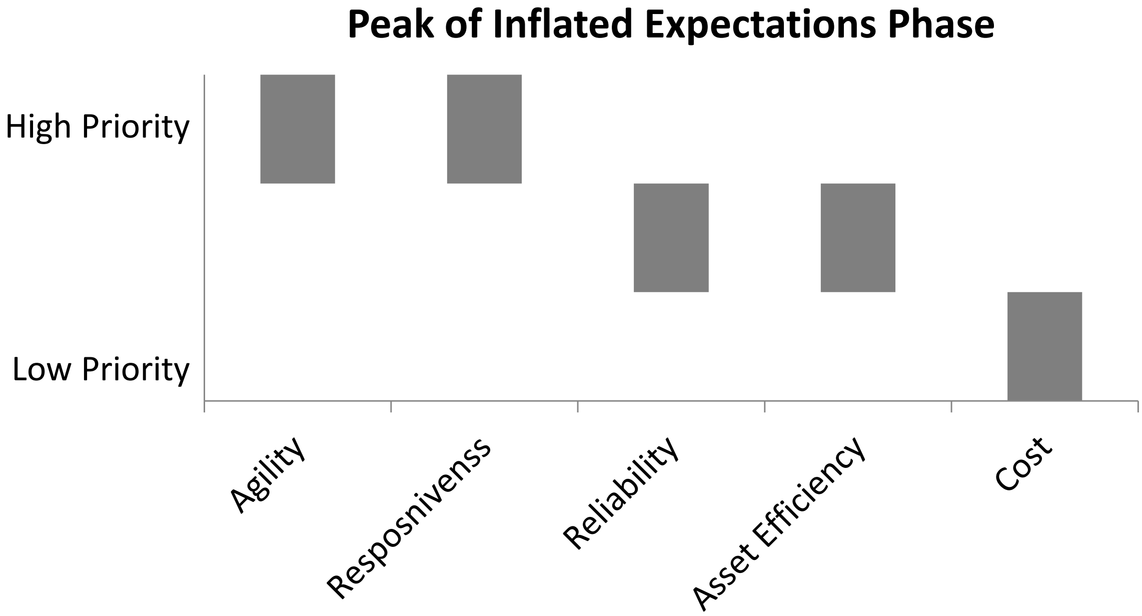

Figure **3**.

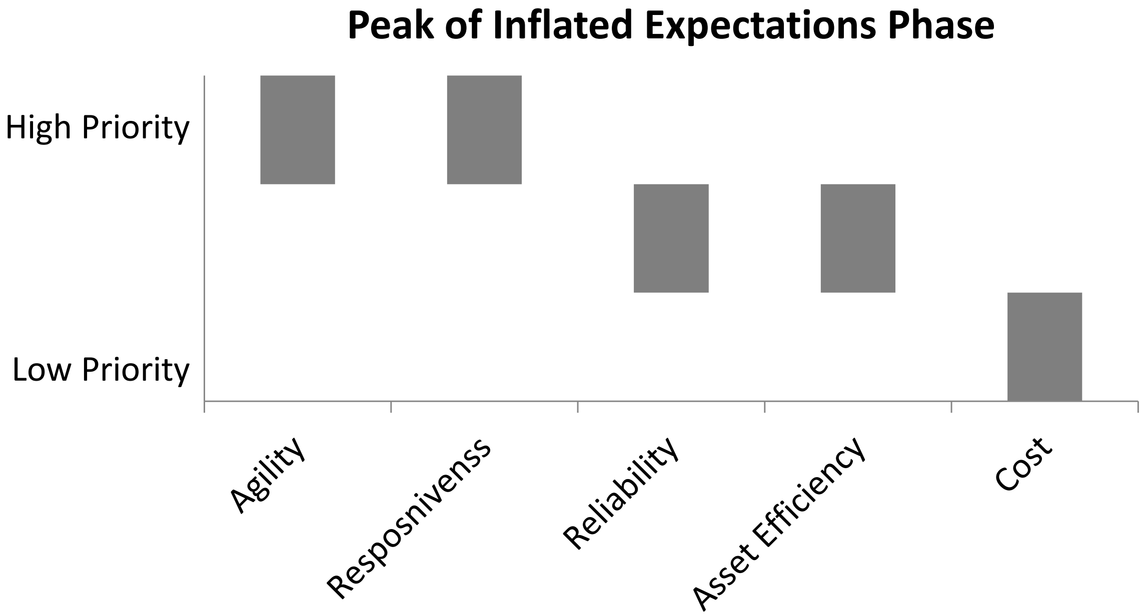

Figure 3. Prioritisation of SCOR performance metrics during the peak of inflated expectations phase

Given the associated focus on responsiveness and reliability, this phase utilizes SCOR best practices such as baseline inventory levels, and pull based inventory (SCC 2012). The importance of implementing pull production and inventory is also attested by Roh et al. (2014, p. 208) To maximize the responsiveness and reliability, best practices include the implementation of Kanban manufacturing and inventory optimization, which ensure the efficiency of assets (Oh and Shin, 2012). Additionally, emerging practices identified within this stage include Supply Network Planning, which proactively identifies future inventory distribution to enable a close match between supply and demand.

Phase 3: Trough of Disillusionment

The trough of disillusionment is a period of market decline for the innovative product, as the hype begins to turn against the product, and market interest drops significantly (O'Leary, 2008). According to product maturity, the product is transitioning from its late emergence to an early growth stage. This phase is connected to an "adaptable" supply chain strategy, which prioritises the consolidation of the supplier base and begins cost efficiency measures (Parlings and Klingebiel, 2012).Early levels of maturity allow for some feedback of the supply chain, and the economic performance of the supply chain is breaking through the emergent stage. The calming of hype presents the best opportunity for consolidating the supplier base, and an additional opportunity to eliminate the inefficiencies that have developed out of convenience during the hyped stages of development (Parlings and Klingebiel, 2012).

SCM research that can be related to this unique hype cycle phase is very scarce. At this point, the supply chain begins to move its suppliers nearer to production and distribution, which on the one hand increases the ability to quickly adapt the supply chain in accord to changing market conditions (Liao et al., 2011) while on the other hand provides opportunities for cost reduction. The decreasing hype and diminishing sales figures during the trough of disillusionment offer a chance for reducing the complexity of the supply chain that responsive supply chains in previous phases had to deal with (Roh et al., 2014). Cost efficiency becomes a relevant part of the SCM strategy for the first time in the life cycle, as dwindling profits will only fuel the downward trend of the trough of disillusionment. The adaptable phase of the supply chain adopts a structure that shifts to changes in customer flows and buying behaviours (Christopher and Holweg, 2011).

With regard to SCOR performance metrics, this phase marks the turn from prioritising customer-focused metrics (agility, responsiveness and reliability) to the internal-focused metrics asset efficiency and cost (SCC 2012, p. i.4). The supply chain can afford to be slightly less responsive than in the previous phase, but makes up for this deficiency with a greater focus on cost reduction and overall asset efficiency through lean planning techniques (Danese et al., 2013). While the management of demand fulfillment is a priority, it is additionally important to do so in a cost efficient manner, and at the lowest cost that does not jeopardise the long-term success of the supply chain (Wagner et al., 2012). The relative prioritisation of SCOR performance metrics in this initial trigger phase of product innovations is summarised in

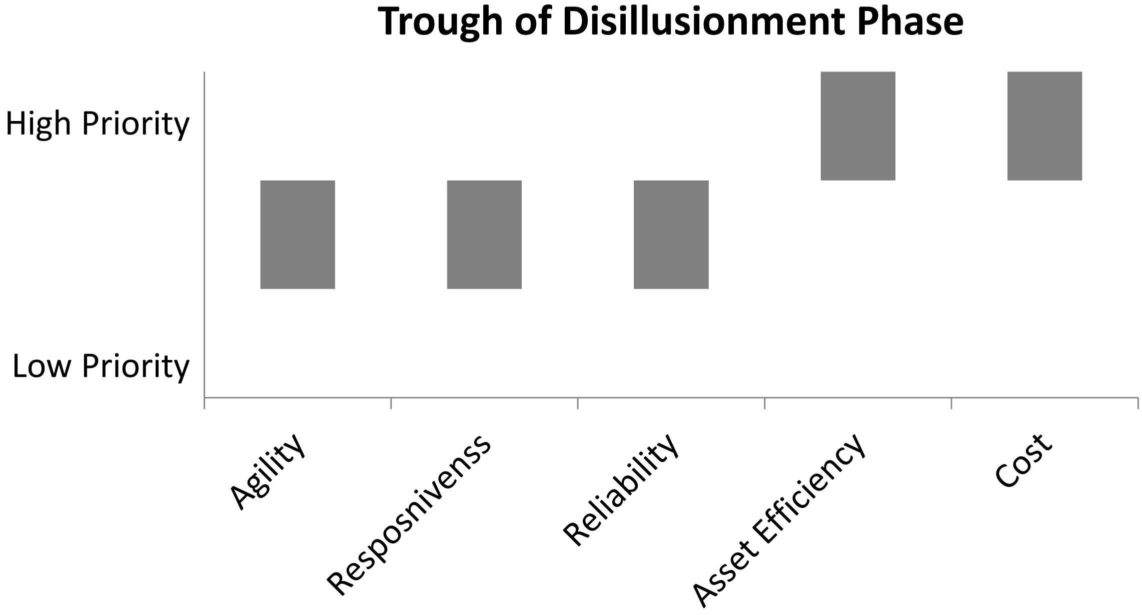

Figure **4**.

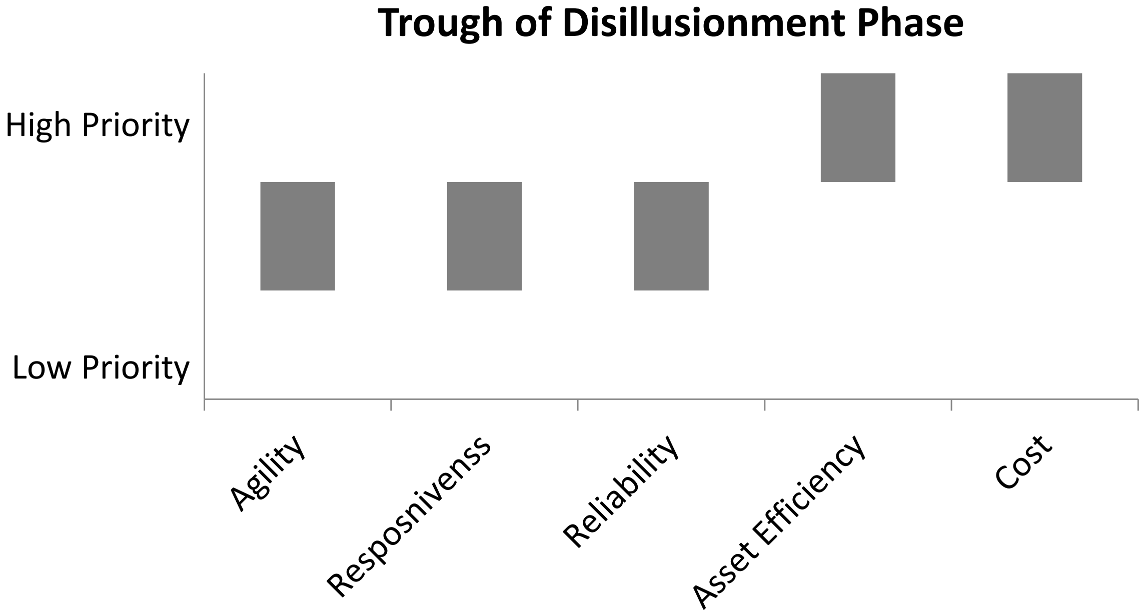

Figure 4. Prioritisation of SCOR performance metrics during the trough of disillusionment phase

Insufficient information prevents accurate demand forecasting, which limits the traditional forms of adaptability available for the supply chain. Yet, SCOR strategies for this stage such as Kaban inventory management still emphasize an adaptable supply chain, and some demand forecasting can still be successfully accomplished. Cost cutting begins to be effective in the long-run, as relationships with suppliers inherently increase the level of reliability, and thus increase the efficiency of the supply chain (Nahapiet and Ghosal, 1998; Liao et al., 2011). Additionally, the need for an agile response upon leaving the trough necessitates the emerging practice of demand forecasting, though SCOR cautions against extensive implementation at this current time (SCC, 2012).

Phase 4: Slope of Enlightenment

In the slope of enlightenment, market adoption begins to build at a steady rate (Linden and Fenn, 2003). This phase is marked by the upward scaling of the supply chain, as it has the market bandwidth to push demand, though contingencies are still necessary (Liao et al., 2011). During this stage, adoption raises from 5% up to 30% of the potential market segment, and the accelerated performance directly leads to increasing profitability (Linden and Fenn, 2003; Lu and Beamish, 2004; Schilling and Esmundo, 2009).

For SCM purposes, the supply chain tends to gain sufficient sales and market information to become able to create a reliable forecast. The applicability and benefits of a forecast begin to grow as sales are now largely determined by the product's fitness. At the same time, ensuring the adaptability of the supply chain grows in importance, as the supply chain must be able to immediately react to increasing demand in order to maintain its market position and capitalize on the opportunity that it is presented. Referring to the original supply chain innovation framework, agility is the right supply chain strategy at this phase (Parlings and Klingebiel, 2012).

Scaling up, in the context of the supply chain, results in an increase in production capacity, which simultaneously affects the potential for profits and risk. One means of combating this risk, especially when market forecasts are in their initial stages and thus unreliable, is to institute a policy of product recovery, which is a functional component of an organic production system (Demeester et al., 2007). Resources become the largest contingency for the supply chain, and the sustainability of the supply chain results from the interaction between the supplies and the firm, as suppliers may potentially become a "weak link" in determining the agility of the supply chain (Cheung and Rowlinson, 2011). Moreover, this is the stage in which a learning model begins to become effective, which is essential for increasing the agility, reliability, and asset efficiency of a supply chain (Sokolov and Ivanov, 2012). With regard to supplier management, entering the growth phase asks focal companies in supply chains to select a strike a balance between long-run contracts with customers (in order to profit from above mentioned learning curve effects) and simultaneously building up alternative suppliers to reduce unilateral dependencies (Wannenwetsch, 2009).

Increase in the hype level create a more sustainable market that reinvigorates forecasting techniques which focus on the agility of the supply chain. Minor perturbations in the market are unlikely to significantly affect the long-term fitness of the product, and the supply chain should thus prioritize its reliability and agility to insulate itself against extreme risk (Ivanov and Sokolov, 2012). Focusing on tapping the potential of a growing market leads to a decreased priority on cost and asset efficiency as companies need to build up capacities. Coordinating supplier bases is critical for the establishment of reliability and sustainability (Liao et al., 2011; Rungtusanathlam and Forza, 2004). The shift over to an agile strategy reduces the costs and asset efficiency of the supply chain but essentially increases the agility without compromising much reliability (Naim and Gosling, 2011).Giese (2012) even states that cost is such a low priority for the agile supply chain that cost KPIs do not need to be integrated into a performance measurement system (Giese, 2012, pp. 151-154). Compared to the adaptable supply chain in phase 3, the agile supply chain responsiveness remains with low priority, as agile planning methods often take time to adapt to perturbations in the market

(Naim and Gosling, 2011). The relative prioritisation of SCOR performance metrics in this initial trigger phase of product innovations is summarised in Figure 5.

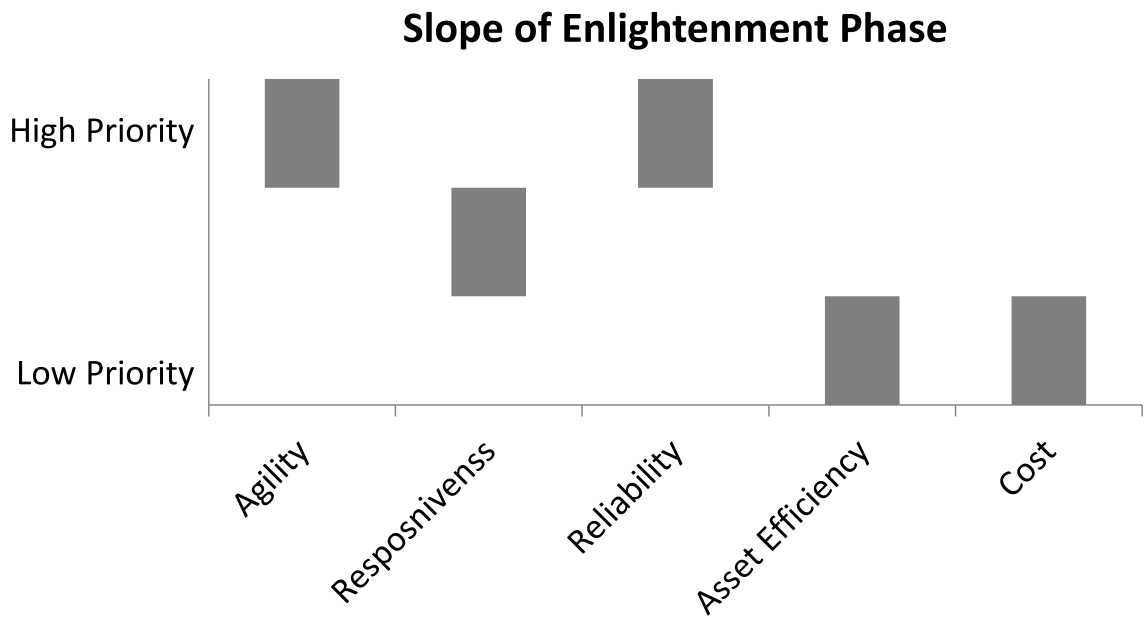

Figure 5: Prioritisation of SCOR performance metrics during the slope of enlightenment phase

This stage introduces the potential for customisation, as a more mature and diverse supply chain is able to better handle the complexity spurred by MTS and customization efforts (Liao et al., 2011). High responsiveness and agility is further accomplished through best practices like a make-to-order strategy, as defined by SCOR. Additionally, risk management is an emerging practice that can serve to ensure the long-term success of the supply chain by maximizing its agility (SCC 2012).

Phase 5: Plateau of Productivity

At this stage, the innovative product's hype cycle ends as the product turns to an established product, and profits begin to diminish (Schilling and Esmundo, 2009). An innovation is considered proven, and thus might transit into a mainstream or functional product, which has a separate set of SCM strategies to abide by. Previous frameworks for guiding supply chains through product life cycles have identified this stage under two possible outcomes, either "efficient" or "leagile" (Mason-Jones et al., 2000). The distinction is based on the priorities and risk potential of the firm as well as the lasting rate of innovativeness of the product (Parlings and Klingebiel, 2012). At this point, assuming that the product is still significantly innovative, the supply chain aims to be hybrid (or leagile synonymously), as it prioritizes agility and asset efficiency, respectively.

With regard to SCOR performance metrics, asset efficiency and cost are most highly prioritiz (Mason-Jones et al., 2000). The focus on asset efficiency and lean planning is consistent through SCM research (Giese, 2012, pp. 154-157; Ojha et al., 2014, Qrunfleh and Tarafdar, 2014). Liao et al. (2011) echo the principles of asset efficiency, and emphasize a means of production that is simultaneously high in volume and low in cost, in order to provide the product or service to market in them most efficient means possible. Relative to the supply chain strategies of the previous stage, the efficient model must still increase its reliability somewhat, to compensate for the decrease in responsiveness, whereas agility decreases for the sake of increased efficiency (Kim and Lee, 2010).

When taking a “leagile” approach instead of a pure efficient strategy, the agility dimension needs to be hedged slightly. By amalgamating lean and agile principles, this style of supply chain is higly reliable, though slightly less responsive than the wholly agile supply chain (Naim and Gosling, 2011). While not nearly as efficient with its assets or costs as the efficient supply chain, the balance between lean and agile approaches nevertheless provides higher efficiency than previous iterations of the supply chain (Naim and Gosling, 2011).

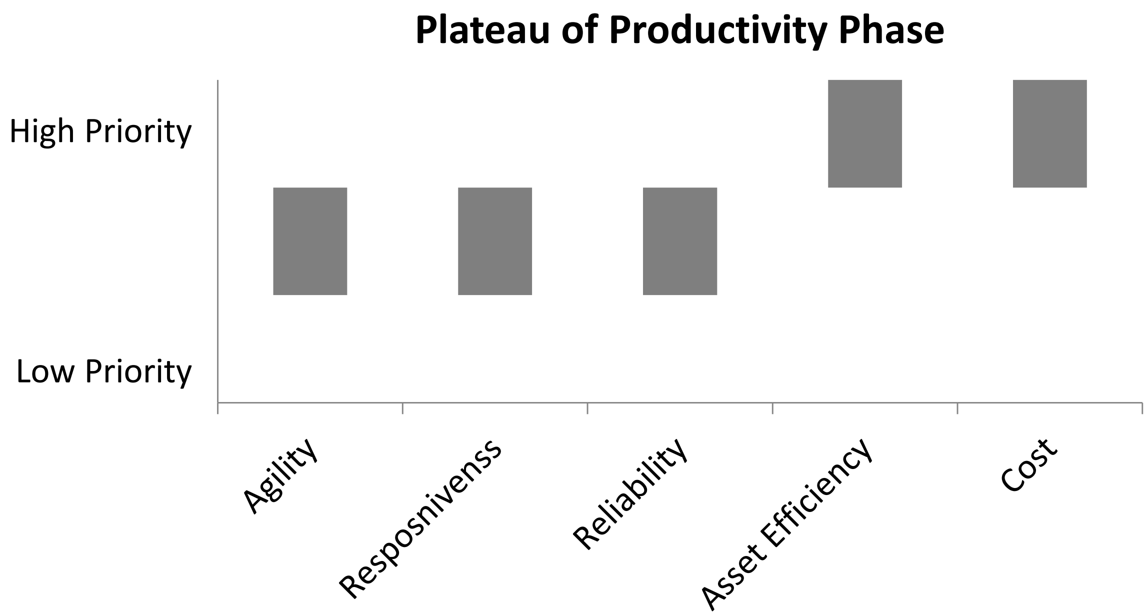

Figure 6: Prioritisation of SCOR performance metrics during the plateau of productivity

The sustainable stage of the supply chain is marked by relatively stable sales forecasts, cost effective logistics, supply chain visibility, and can be accomplished by the integration of suppliers into the means of production (Liao et al., 2011). This stage is marked by the influence of “long term” planning techniques, such as event and risk management, network information management, and a very high potential for market forecasting (Kuhn and Hellingrath, 2002; Ivanov and Sokolov, 2012). Additionally, businesses should begin to further cut costs through transportation optimisation, and begin optimal market acquisition (Demeesteer et al., 2007).

Since supply bottlenecks are not to be expected in this mature phase, procurement and supplier management should focus on reducing procurement costs. Suitable methods for achieving this goal include the Total Cost of Ownership approach, for instance (Wannenwetsch, 2009). Given the connection and familiarity between firms, inter-organizational learning can further decrease costs, and especially facilitate principles such as transportation optimisation (Mellat-Perast, 2013).

4. Conclusion and Further Research

The changes in the lifecycle of an innovative product manifest themselves in terms of market visibility and demand, which in turn necessitate a dynamic supply chain model. While many of the principles of generalized supply chain development apply similarly to innovative product life cycles, there is an especially significant focus on agility and responsiveness when the market is not attenuated to a particular product. In supply chains dealing with innovative

products, these changes must occur especially quickly, as phases are often compressed (Parlings and Klingebiel, 2012). The supply chain associated with an innovative product life cycle must incorporate an additional set of hedges, particularly in the intermediate stages, in order to adapt to a changing market environment and maintain financial success. Once stable growth forecasts can be achieved, the product reverts to a standard product life cycle, and can implement the proven tactics of SCM to effectively manage risk and cost efficiency.
The findings of this paper support metric-driven models for SCM, and the use of a prioritisation of the SCOR performance attributes responsiveness, reliability, agility, asset efficiency, and cost. During each phase of the product life cycle, the supply chain must prioritise each of these categories to a different extent in response to a changing market environment. The extended framework provides guidance for setting up boundaries for KPI systems by relating supply chain strategies to SCOR performance attributes. Moreover, the framework gives strategies that can help implement these changes.

Further research must be done on the means to assess movement through the phases of the innovative product life cycle. The rough prioritisation of performance attributes provided in this contribution needs to be broken down to the performance metrics (KPIs). As changes in the innovative product life cycle occur, this can help to distinguish between typical and abnormal variance in supply chain effectiveness by measuring the deviation within acceptable channels. Behaviour outside these norms suggests that a significant change in SCM strategy is needed (Parlings et al., 2013b).

The current model is practical as a general proof-of-concept, but more specialized models can potentially offer more insight for certain industries. Moreover, the model currently has a significant limitation in that the priorities remain empirically undefined, and it is of significant interest to determine what values are truly acceptable. Hence, further research should focus on validating the findings through empirical investigation and case studies. That notwithstanding, this research represents a more actionable framework for SCM strategy for innovative products.

5. Acknowledgement

The authors gratefully acknowledge the German federal ministry of education and research (EffizienzCluster LogistikRuhr– research project SCD 01IC12L03B). Furthermore, the authors appreciate Brent Reach’s research support that has been made possible by Princenton’s Keller Center REACH exchange program in cooperation with TU Dortmund.

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Taxonomy of SME manufacturing strategies in a structurally changing economy

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Abstract

This research seeks to further test the classic manufacturing strategy taxonomy by Miller and Roth (1994). Cluster analysis is conducted on a data set collected from a sample of Finnish manufacturing SMEs, in a context where the country is undergoing a phase of structural change in terms of its industrial base. The results suggest a four cluster solution, with some similarities with the classic three cluster solution; however, significant differences are observed as well, suggesting perhaps a distinct taxonomy for SMEs. Taking into consideration the context of the research, with much policy emphasis placed on manufacturing SMEs as the backbone of developed economies, locked in competition with emerging economies, the findings also suggest a lack of servitization capabilities in particular and other distinctive manufacturing capabilities in general, among the Finnish manufacturing SMEs, on average.

Keywords: manufacturing strategy, SME, cluster analysis, Finland, structural change

1. Introduction

The role of small and medium sized enterprises (SME) has increased during the decades as large corporations have reduced their basic research budgets, while short time frame applied product development and business acquisitions have been used instead. In other words, SMEs are no longer just a source of raw materials, components or semi-finished items, but they are increasingly source of new ideas, new products and "complete package" supply with OEMs brand put in the product. Therefore, requirements for price, quality, delivery and flexibility have increased, and SMEs have to provide these with advanced IT systems (Haug et al., 2011), development resources (Arrunada and Vázquez, 2006; Hilmola et al., 2005) and financing ability (Ma & Hilmola, 2007).

Based on recent empirical research conducted in Spain for different sized companies (Minguela-Rata et al., 2014), it was shown that medium sized companies are most innovative, and innovation takes place in mode of collaboration with customers, which are typically larger corporations. Also age plays important role as innovation is present most often in younger companies. It could be said that large corporations are increasingly talking about innovation and seeking opportunities, but these are tried to be found from stakeholders and active technology licensing, business acquisition and divestment activity. Phenomenon of *open innovation* is one of the hottest topics within innovation discipline, and it does not only emphasize collaboration between companies, but with that of universities, research laboratories and government (Naqshbandi & Kaur, 2014).

As initiating new companies, it is important that risk finance, markets for products and research and development funding (and organizations) are available. Therefore, it is justified that growing GDP results in good environment for SME establishment and sustainability (Kshetri, 2014). With SME serving manufacturing sector or large tangible projects, it is important that share of imports and exports is having high share out of GDP and imports and exports is growing (Kshetri, 2014). This ensures manufacturing SMEs to have legislative (coupled together with low bureaucracy) and financial support from government as well as financial sector, and supply of competence and resources from pool of labour. Our research environment of Finland used to be such exemplary place for SMEs – foreign trade was annually growing and having high share from GDP. Also GDP was in constant and admired growth mode. However, after financial crisis and global credit crunch of 2008-2009 everything changed and development trajectories are pointing to unfavourable direction. Still today Finnish GDP is below 2008 level (year 2013 it was in real terms roughly five percent lower; see Statistics Finland, 2014), and both imports (nearly -7 % in 2013) and especially exports (nearly -15 % in 2013) are lower than what they were in 2008 (Finnish Customs, 2014). Situation has been lasting for years, and therefore remaining companies in manufacturing must have carefully developed their strategies to survive. Also increasing competition from emerging markets (Low, 2007; Lorentz et al., 2007; Shah and Jolly, 2011; Laisi et al., 2012; Sodhi and Tang, 2013), like Eastern Europe and Asia, are adding further pressure to perform together with strong currency of Euro.

Research problem of this work is two-faced, and it is firstly related to the possible grouping or classification of manufacturing SMEs in Finland. Secondly under interest is how this compares to that of foreign companies. We address the following research questions:

RQ1: Can a taxonomy of SME manufacturing strategies be established for the Finnish context?

RQ2: How does this compare with the manufacturing taxonomies presented in prior research?

We contribute to the literature on manufacturing strategy taxonomies, and examine how current understanding of manufacturing strategies applies to SMEs, and whether the context with significant structural changes is somehow reflected in the results. With much resting on the shoulders of SMEs, it is paramount to understand how SMEs address competitive pressure in a structurally changing economy.

2. Taxonomic research on manufacturing strategies

Practical design and implementation of a manufacturing system that supports business aims is a complex task, involving dozens of variables. Configuration models, defined as “multidimensional profiles used to describe organizational, strategy, or process types”, have been suggested as a useful approach to addressing the requirement of environmental and internal fit of the manufacturing strategy (Bozarth and McDermott, 1998). Essentially, the configuration approach may suggest a limited number of viable strategies, organization types, manufacturing tasks and so forth, with identified outcomes, making the management task simpler.

Configuration models are typically divided into taxonomies and typologies, each representing unique combination of attributes. Typologies are often conceived, perhaps mistakenly (Bozarth and McDermott, 1998), as conceptual, and taxonomies empirical; however, all useful typologies should be grounded in empirical evidence (Meyer et al., 1993). According to Bozarth and McDermott (1998), typologies describe ideal types of configurations, perhaps unattainable by any organization, whereas taxonomies essentially classify empirical observations into mutually exclusive and exhaustive groups. Good taxonomies generate insight through description, enable prediction, and are relatively unaffected by techniques or sample data used in the creation of the taxonomy, the last being the key empirical test (Bozart and McDermott, 1998).

One of the most influential manufacturing strategy taxonomies has been the one proposed by Miller and Roth (1994), which is based on eleven taxons, presented and defined in Table 1. Their empirical work focused in North America, and large firms, and resulted in three distinct manufacturing strategy clusters, namely Caretakers, Innovators and Marketeers.

Table 1. Taxons used in the original study of Miller and Roth (1994)

No.	Taxons (competitive capabilities)	Definitions
1	Low price	The capability to compete on price.
2	Design flexibility	The capability to make rapid design changes and/or introduce new products quickly.
3	Broad product line	The capability to deliver a broad product line.
4	Volume flexibility	The capability to respond to swings in volume.
5	Conformance quality	The capability to offer consistent quality.
6	Performance quality	The capability to provide high performance products.
7	Delivery speed	The capabiliuty to deliver products quickly.
8	Delivery dependability	The capability to deliver on time (as promised).
9	After sales service	The capability to provide after sales service.
10	Broad distribution	The capability to distribute the product broadly.
11	Advertising	The capability to advertise and promote the product.

In later works, seeking to test the resulting taxonomy through further empirical evidence, Frohlich and Dixon (2001) used longitudinally replicated global data and similar data collection instruments; however, some of the taxons (broad distribution, advertising) were dropped in latter data collection rounds. Frohlich and Dixon (2001), being largely silent on respondent characteristics in terms firm size, found partial support for the three strategy-types of Miller and Roth (1994); however, Marketeers were later replaced by Designers, and three other unique strategies were identified as well: Idlers, Servers, and Mass Customizers.

Catering for the interest on understanding manufacturing strategies of firms in the factory of the world, Zhao et al. (2006) tested the Miller and Roth (1994) taxonomy (without the marketing oriented two taxons identified earlier) in the Chinese context, choosing to sample from a typical city, Tianjin. The results of Zhao et al. (2006), with sample including a significant portion of SMEs as well, suggest a taxonomy different from the strategic clusters of Miller and Roth (1994). The Chinese clusters suggested such strategy types as Quality Customizers, Low Emphasizers, Mass Servers, and Specialized Contractors.

In order to get a sense of cluster profiles suggested by prior research, we collected taxon variable means from each of the above mentioned contributions and compared the cluster profiles graphically. Due to different measurement scales used in the studies (1-to-7 Likert scale in Miller and Roth, 1994, and Zhao et al., 2006; 1-to-5 Likert scale in Frohlich and Dixon, 2006), we normalize the data to a range of -1 to 1, with 0 as the central point (Table 2).

Table 2. Comparison of cluster profiles from previous research (normalized means; MR = Miller and Roth, 1994; FD = Frohlich and Dixon, 2001; Z = Zhao et al., 2006; green used for values above zero, max 1; red used for values below zero, min -1)

Normalised means [-1,1]	Caretakers (MR)	Marketeers (MR)	Innovators (MR)	Idlers (FD)	Servers (FD)	Mass Customizers (FD)	Designers (Western Europe; FD)	Quality Customizers (Z)	Low Emphasizers (Z)	Mass Servers (Z)	Specialized Contractors (Z)
Low price	0,687	0,567	0,487	-0,500	0,280	0,375	0,510	0,450	-0,200	0,900	0,813
Design flexibility	0,370	0,357	0,660	0,250	-0,295	0,375	0,570	0,563	-0,350	0,733	-0,127
Broad product line	0,333	0,433	0,260	-0,250	-0,120	0,185	0,580	0,463	-0,367	0,903	0,570
Volume flexibility	0,057	0,347	0,020	-0,500	-0,475	0,125	0,455	0,557	-0,467	0,780	0,050
Conformance quality	0,610	0,927	0,917	-0,125	0,435	-0,125	0,755	0,767	0,000	0,947	0,737
Performance quality	0,057	0,690	0,793	-0,125	0,485	0,185	0,790	0,303	0,033	0,773	0,667
Delivery speed	0,517	0,530	0,467	-0,750	0,405	0,000	0,720	0,173	-0,300	0,843	0,893
Delivery dependability	0,667	0,703	0,763	-0,750	0,385	0,060	0,790	0,383	-0,133	0,770	0,197
After sales service	-0,353	0,423	0,507	-0,500	0,555	-0,065	0,790	0,433	-0,400	0,817	0,373

In terms of the clusters by Miller and Roth (1994), Caretakers are focused on low price, as well as conformance quality and delivery (Table 2). Both Marketeers and Innovators are very quality focused; however, Innovators emphasize design flexibility and after sales service, whereas Marketeers emphasize low price and broader product line, and more flexible volume (marketable manufacturing processes).

Frohlich and Dixon (2001) discovered a breed of manufacturers with general low emphasis, the Idlers. Servers focus on after sales service, with adequate processes (quality, time), with little flexibility and narrow product line. Designers focus on quality and time-based capabilities, with after sales capability as well; however, in comparison to the Innovators cluster of Miller and Roth (1994), with a slightly diluted design flexibility, but broader product line and enhanced volume flexibility (Table 2).

Zhao et al. (2006) also found a lack-luster cluster with a fitting name: Low Emphasizers. In contrast to Idlers, this cluster is relatively more quality focused, and less design flexibility focused. Quality Customizers focus on conformance quality with flexibility (both design and volume), with some emphasis also on broad product line. Mass Servers attempt strong emphasis everywhere, thus the fitting name, reflecting "the attempt to service a ''mass'' of customers through a variety of manufacturing capabilities and after-sales services." (Zhao et al., 2006, 629). Specialized Contractors are essentially contract manufacturers (low design flexibility meaning perhaps no own product designs), with focus on speed, cost, quality, but relatively low volume flexibility (Table 2).

As the existing evidence is perhaps slightly biased towards large firms, especially in terms of highly developed economies, and as the evidence on the stability of the Miller and Roth (1994) taxonomy across data and samples appears mixed, we contribute to the literature with a further empirical test with focus on SMEs in developed economy undergoing structural changes.

3. SMEs and structural changes in the Finnish economy

Finland has been transforming from industrial society to more service sector and public sector dominated country. Downward trend in industrial work could be detected back to early 1990’s, when Soviet Union collapsed and most important export market deteriorated for years to come. This was not easy time as Russian economic recovery in this decade was severely interrupted with Russian sovereign debt default and followed significant devaluation of its currency. After difficult decade of 90’s situation in manufacturing sector was little bit improved and employment even increased in the early 2000 (mostly due to emerging electronics sector and moderately high demand of paper in Europe and North America). However, globalization and internationalization of manufacturers (e.g. through FDI and acquisitions) resulted in the continuous job-loss. As Figure 1 illustrates industrial working places in Finland have declined by more than 20 % in the period of 2000-2013.

In general structural changes have followed global economic bubbles of recent decades. In tech bubble of 2001 Finnish employment started to decline rapidly in industrial sector. Vicious cycle was mostly driven by the need of electronics sector to find cost savings and profitability. Remedy was offshoring and outsourcing. Similar kind of negative feedback loop cycle was released by the global financial crisis of 2008-2009. Again vicious cycle rippled through economy – manufacturing units were shut down completely from various sectors, and companies related to paper production as well as electronics cluster were in severe trouble. This of course resulted in several bankruptcies. Figure 1 illustrates revenue of four most important export industry sub-sectors of Finland. As could be clearly detected, revenue of electricity and electronics (appliances) industry, metal industry and forest industry was severely hurt by 2008-2009 economic hardship. Only bright spot of leading industrial sector has been chemicals production, led by oil refining and making oil from renewable sources. However, this of course has partly been supported by high energy prices in global markets.

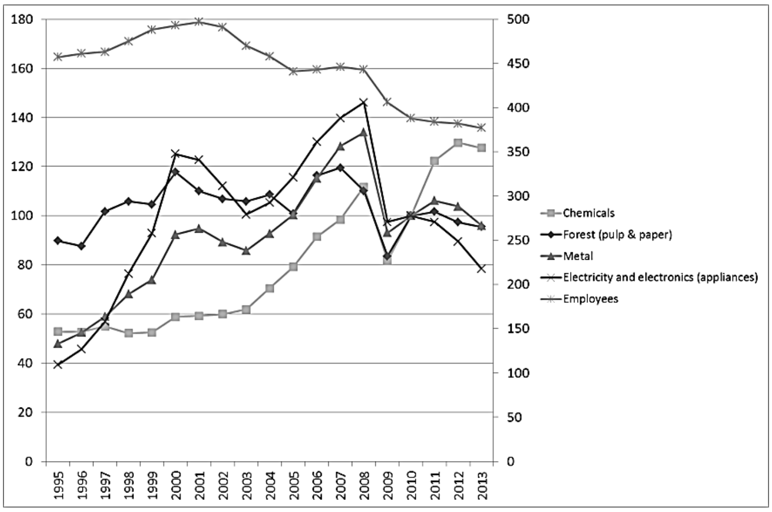

Figure 1. Employment in industrial companies and revenue development of four most important Finnish sub-sectors of industry. Source (data): Statistics Finland (2014)

Table 3. Value of Finnish exports in different sub-groups during years 2004, 2008 and 2012. Source (data): Finnish Customs (2014)

Export Item	*Year 2004*
Electrical and electronics (appliances)	10,495,183,301 €
Paper and paperboard	8,236,643,020 €
Metal Industry Products	5,860,513,387 €
Iron and Steel	3,319,072,443 €
Wood and wood products	2,504,275,512 €
Fuels, oils and other chemicals	2,088,880,074 €
Vehicles (other than railway and trams)	1,856,716,134 €
Plastics	1,335,409,858 €
Optical and medical products	1,329,947,503 €
Ships and boats	968,142,986 €
Others	10,534,238,920 €
Total	48,529,023,138 €

Export Item	*Year 2008*
Electrical and electronics (appliances)	13,508,277,548 €
Metal Industry Products	9,632,821,244 €
Paper and paperboard	7,818,995,582 €
Fuels, oils and other chemicals	4,489,597,687 €
Iron and Steel	4,227,388,207 €
Vehicles (other than railway and trams)	3,706,862,142 €
Wood and wood products	2,284,979,810 €
Plastics	1,794,746,917 €
Optical and medical products	1,651,063,153 €
Ships and boats	1,506,486,864 €
Others	14,301,791,663 €
Total	64,923,010,817 €

Export Item	*Year 2012*
Metal Industry Products	8,014,299,142 €
Paper and paperboard	7,410,613,895 €
Fuels, oils and other chemicals	6,201,816,744 €
Electrical and electronics (appliances)	5,689,243,864 €
Iron and Steel	3,788,195,152 €
Wood and wood products	2,097,626,942 €
Optical and medical products	2,035,624,364 €
Plastics	1,995,212,086 €
Vehicles (other than railway and trams)	1,742,342,328 €
Pulp	1,374,548,136 €
Others	15,417,549,352 €
Total	55,767,072,005 €

Much more accurate manner to observe ongoing structural change of Finnish industrial sectors is by examining value of export in key export item groups (as revenue of industrial companies is always hard to interpret only to one country). Export data was gathered from three years 2004, 2008 and 2012 (Table 3). Before crisis electrical and electronics appliances were having clearly the lead in export activity, but thereafter significant decline took place. Change from year 2008 to 2012 was nearly 58 % decline (see Table 1 bold text). Also metal industry product export has been hurt, but with approx. 17 % decline. Smaller declines are present in paper and paperboard, iron and steel, and wood exports. Only very bright spot has been optical and medical products (+23.3 % from year 2008), fuels and oils (+38.1 %), and plastics (+11.2 %). Currently Finland is back partially in old days of 80's as paper and paperboard together with pulp are largest export industry of the country (in Table 1 highlighted with bold and underlined).

Another positive aspect of restructuring process of economy in Finland has been the response of private sector and the inauguration of new companies. Actually the number of companies is continuously increasing, and while large corporations have mainly reduced the jobs, SMEs, and especially small ones, have been able to increase the amount of employment (European Commission, 2013; Federation of Finnish Enterprises, 2014). This is of course mostly so in software and service sector SMEs, but amount of industrial companies in nationwide register has continued to increase during the crisis time, and is the main source of value added among SMEs (European Commission, 2013). In manufacturing sense Finland is of course distantly located from the main markets, but it has some considerable strengths. For example, lower manufacturing costs could be implemented by transferring manual manufacturing phases partly to Baltic States and/or Russia. Also acquiring raw materials from east is providing occasionally cost advantage.

4. Methodology

4.1 Data collection and sample

The empirical data for this study was gathered by using a survey method by means of an Internet-based survey questionnaire in March-April 2014. The population for this study was comprised of SMEs and large companies in Finland from 24 industry groups in manufacturing (SIC codes 10–33). Non-manufacturing and micro companies were excluded from the scope of this research. According to the data of *Statistics Finland*, there were 2,541 SMEs and large firms in the manufacturing sector in Finland in 2013.

Contact information of companies was obtained from the *Intellia database* (i.e., a database containing information over 450,000 companies operating in Finland). The chosen database was the preeminent possibility to get contact information comprehensively about the whole population. The distribution list included 3,751 email contacts in 1,945 different companies.

An internet survey was determined to be an appropriate and cost-effective method in order to achieve the objectives of this study. An inquiry was conducted with web survey software, and the web questionnaire was initially tested with a small group of willing suppliers. An invitation to participate in the questionnaire was sent to 3,751 personal email addresses in 1,945 different companies followed a week later by a first reminder message. On the whole, reminder messages were provided to participants, who did not respond, four times. If more than one response were received from the same company, the most complete one was chosen. In total, 244 valid questionnaires were used for further analysis, with a response rate of 12.6 percent. Due to our focus on SME manufacturing strategies, we limit our analysis to the SMEs in the sample. The share of SMEs among the respondents was 190 enterprises (Table 4.).

Table 4. Frequency distributions of the respondents (SMEs, n = 190).

Turnover (2013)			**Employees (2013)**		
Turnover (millions, €)	*Frequency*	*%*	*Employees*	*Frequency*	*%*
2–5	66	34,7	10–25	52	27,4
5-10	38	20,0	26–50	68	35,8
10-20	42	22,1	51–100	37	19,5
20-50	44	23,2	101–250	33	17,4
Total	**190**	**100**	***Total***	**190**	**100**

Assessing nonresponse bias is an essential part of the survey process. Nonresponse bias refers to the bias that exists in the data as respondents are different from nonrespondents with regards to important characteristics, and therefore generalization is problematic. In this study the representativeness of the sample is based on comparison between respondents and nonrespondents on characteristics known a priori, which is a technique to detect the existence of nonresponse bias (Wagner & Kemmerling 2010).

Prominent differences between respondent and nonrespondents, in terms of known economic information, were not found. In the present study, the nonresponse bias was approached via t-tests comparing key ratios (e.g. turnover, operational profit, profit margin) between respondents and nonrespondents. Statistical significance was based on two-sided tests evaluated at the 0.05 level of significance. The results supported the assumption that there was no nonresponse bias. A moderate difference between respondents and nonrespondents was observed in the size of companies (Figure 2).

In addition to comparison between respondents and nonrespondents, we used extrapolation to examine nonresponse bias (Armstrong and Overton 1977; Wagner & Kemmerling 2010). Extrapolation is one of the most widely used techniques, and it is based on the assumption that late respondents are similar to nonrespondents and if there is no difference between early and late respondents, generalization is possible. Also by using this method, no significant differences were found in our sample.

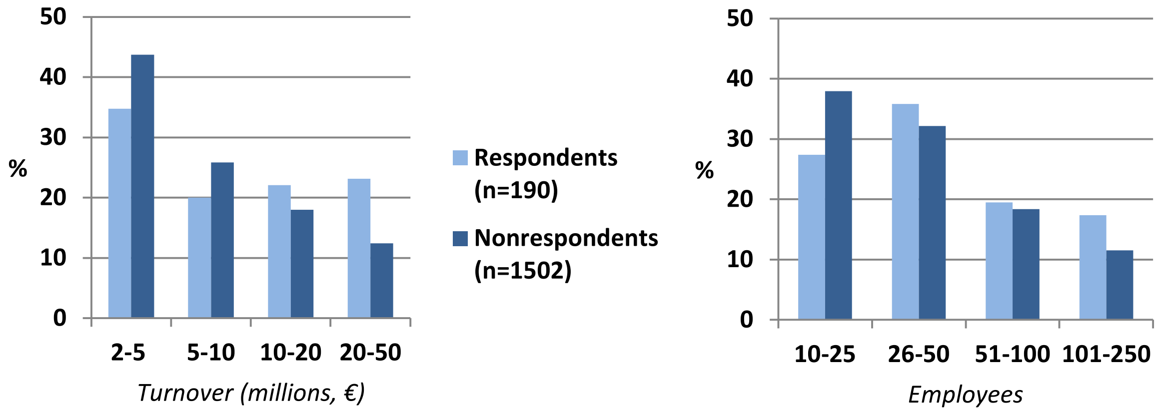

Figure 2. Comparison between respondents and nonrespondents (SMEs).

4.2 Variables

In order to measure manufacturing strategies of Finnish SMEs, we draw on the extant research as was elaborated earlier. Table 5 shows evolution of taxons used in previous research, and the reliance of the current study on the revised set of taxons as suggested by Zhao et al. (2006). Here the original design flexibility of Miller and Roth (1994) is broken down into two separate variables, and the more marketing related broad distribution and advertising are dropped.

Table 5. Comparison of taxons across studies (cf. Zhao et al. 2006)

No.	Competitive capabilities	Miller and Roth (1994)	Frohlich and Dixon (2001)	Zhao et al. (2006)	Current study
1	Low price	X	X	X	X
2	Design flexibility	X	X	..	..
2a	Ability to make rapid changes to products/ services	..	..	X	X
2b	Ability to introduce new products/services	..	..	X	X
3	Broad product line	X	X	X	X
4	Volume flexibility	X	X	X	X
5	Conformance quality	X	X	X	X
6	Performance quality	X	X	X	X*
7	Delivery speed	X	X	X	X**
8	Delivery dependability	X	X	X	X***
9	After sales service	X	X	X	X
10	Broad distribution	X	..	..	..
11	Advertising	X	..	..	..

*exact back-translation “superior quality”
** exact back-translation “short delivery time”
***exact back-translation “correct timing of deliveries”

Each of the taxon variables are measured in a 1-to-7 Likert scale, with response options ranging from “No significance” to “Critical significance” to the question: “Please assess the significance of the following factors to the company at the moment." Eighth response option was provided as the "No response" alternative, eliminating forced assessments.

Data on additional background variables were collected as follows. Respondents' turnover for year 2012 was collected from the sampling database (TURNOVER; in EUR). The extent of supply was determined by asking for the percentage shares of the respective supply arrangement from the total volume by monetary unit (FOREIGN; in 0-100%).

Furthermore we inquired perceptions of the respondents on several statements, relating to environmental dynamism, level of technological advancement and innovation, as well as business perspectives (cf. Bierly and Daly, 2007). More specifically the following statements were measured on a seven-point Likert scale, ranging from "completely disagree" to "completely agree": (1) the company's markets change faster than average (CHANGESPEED), (2) the company's markets change more unpredictably than on average (CHANGEUNPREDICT), (3) the company can be considered as part of technology industries (HIGHTEC), (4) the company makes significant investments into new product development (PRODUCTDEV), (5) the company makes significant investments into process development (PROCESSDEV), and (6) business perspectives for our company are positive during the next 12 months (PERSPECTIVES).

4.3 Analysis method

The method of cluster analysis is selected for the research, as it enables the classification of cases, respondents, or more generally, objects, and therefore enables the determination of taxonomies of for example manufacturing firms based on their employed strategy. The cluster analysis is characterized with many weaknesses, and therefore it has been considered a subjective method; however, a strong conceptual basis improves enables validity, as the extant research has provided ample results on which to reflect our methodological choices and conclusions.

Sample representativeness related issues were considered earlier, and we proceed to cover other key issues in cluster analysis. Analysis for the detection of potential outliers does not suggest action to omit any cases from the data. We proceed initially without within-case standardization, and there is also no a need to standardise across variables, as all are measured by the same scale (Hair et al., 2010). Some of the variables appear correlated (low to medium) suggesting possible multicollinearity and uneven influence on cluster solution; however, we retain all the variables in order to maintain comparability with prior research.

As all the clustering variables are metric, we follow an approach similar to both the studies of Frohlich and Dixon (2001) and Zhao et al. (2006), and use the two-step combination clustering procedure, in which a hierarchical technique is first used to determine the applicable cluster solutions and the appropriate number of clusters (we use Ward's method with squared Euclidean distance, as it tends to generate clusters that are homogenous and relatively equal in size; Hair et al., 2010), with resulting outcomes inputted into a non-hierarchical algorithm. As Lehmann (1979) suggests, considering the sample size n (191), the appropriate number of clusters should be between $n/30$ and $n/60$, i.e. from three to six in our case, allowing us to compare with the classic results of Miller and Roth (1994).

In the second phase we conduct a K-means non-hierarchical analysis, and resort to random initial seeds suggested by SPSS within an optimization algorithm that allows for reassignment of observations among clusters until a minimum level of heterogeneity is reached. We test the stability of resulting clusters, by sorting data by the share of foreign supply (FOREIGN), and observing stability through cross-tabulating cluster membership with pre-sort and post-sort cluster membership variables. We further assess criterion validity, by testing the prediction power of the cluster membership variable on some of the background variables of the study. Furthermore, we test the alignment of our results with the results of previous research by using rank correlation analysis for comparing the relative ranking of taxons between clusters.

5. Data analysis and results

Analysis of the agglomeration coefficient produced by the hierarchical Ward's method (with a scree-plot), suggests that the average proportionate increase in heterogeneity to next stage across eight- to two-cluster solution stages is 8.69%, and so as the first higher than average such a value occurs as solutions move from a four-cluster solution to a three-cluster solution (8.89 %), we suggest the four-cluster solution as a possible stopping point. However, given the prior literature's influence on our research aims, and the desire to allow more clusters to emerge (Ward's method tends to suggest to few clusters; Hair et al., 2010), we retain the five- and three-cluster solutions as plausible candidates for the final result.

We proceed to conduct the K-means non-hierarchical analysis, and resort to random initial seeds suggested by SPSS within an optimization algorithm that allows for reassignment of observations among clusters until a minimum level of heterogeneity is reached. The resulting five-cluster solution suggests two large clusters (92 and 48 observations), and three small to very small clusters (22, 17 and 1 observations), whereas the four-cluster solution suggest two large clusters (92 and 53 observations) and two small clusters (21 and 14 observations). The three-cluster solution suggests cluster sizes of 98, 52 and 30. We select the four cluster solution for our main thrust, in order to not overlook small but significant clusters in the data.

5.1 Four-cluster solution

Table 6 presents the variable means and ranks as per variables in a cluster for the four-cluster solution (produced by the non-hierarchical algorithm). One-way ANOVA analyses suggest that there are statistically significant differences among the means as per clusters, indicating that the cluster solution is adequately discriminating observations.

Table 6. Mean values and ranks for taxons in the four-cluster solution (non-hierarchical)

Var.		Mean values (ranks per cluster)					
No.	**Variables (compet. capabilities)**	**1**	**2**	**3**	**4**	**F**	**Sig.**
1	Low price	4.00 (8)	5.83 (6)	6.14 (2)	5.11 (6)	20.32	0.00
2	Ability to make rapid changes to p&s	4.21 (5)	5.93 (4)	5.62 (7)	5.15 (5)	19.77	0.00
3	Ability to introduce new p&s	4.36 (3)	5.76 (7)	3.81 (9)	4.62 (8)	28.76	0.00
4	Broad product line	4.21 (5)	5.16 (10)	5.29 (8)	4.00 (9)	19.49	0.00
5	Volume flexibility	3.93 (9)	6.09 (3)	5.81 (6)	5.79 (2)	23.03	0.00
6	Conformance quality	4.36 (3)	6.15 (2)	6.10 (4)	5.83 (1)	22.18	0.00
7	Performance quality	3.93 (9)	5.66 (8)	5.86 (5)	5.32 (4)	15.44	0.00
8	Delivery speed	4.93 (1)	5.90 (5)	6.14 (2)	5.09 (7)	16.26	0.00
9	Delivery dependability	4.57 (2)	6.35 (1)	6.52 (1)	5.70 (3)	32.35	0.00
10	After sales service	4.21 (5)	5.33 (9)	2.52 (10)	3.62 (10)	65.39	0.00
	Cluster sample sizes	14	92	21	53		0.00

p&s = products/services

Assessment of cluster stability by sorting the data by the variable FOREIGN, rerunning the non-hierarchical analysis, and cross-tabulating for cluster memberships switches by the pre-sort and post-sort cluster membership categorical variables, suggests that the four-cluster solution is stable with 15% of the observations reassigned to a different group (Hair et al., 2010). Examining the cluster means in terms of the taxons graphically, allows us to attempt profiling the clusters (Figure 3).

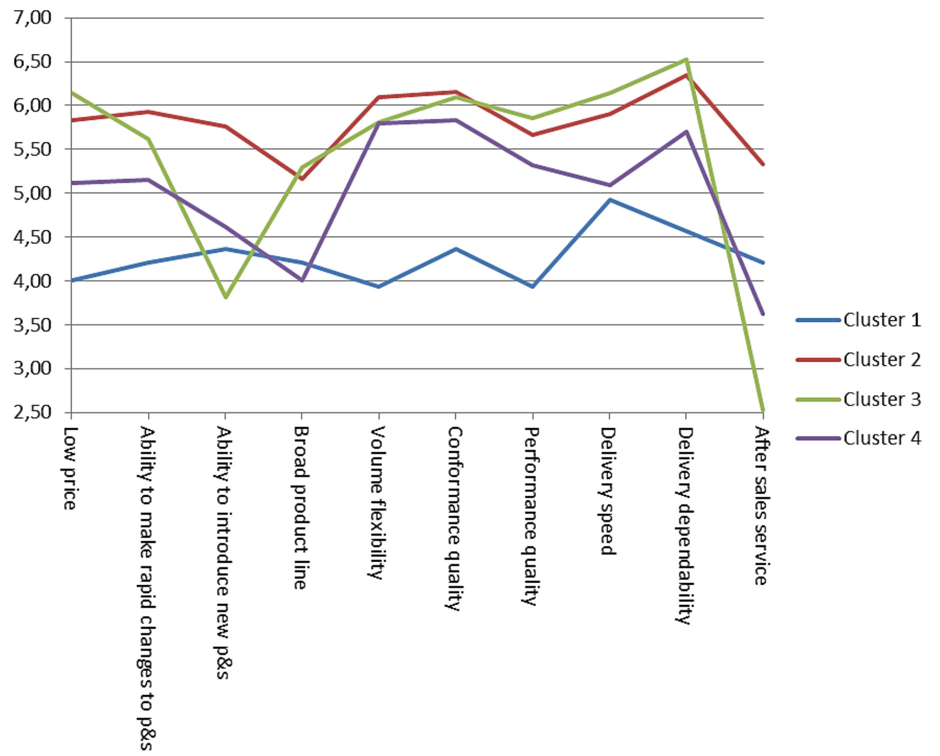

Figure 3. Mean-based profiles for the four cluster solution

Cluster 1 appears overall to have relatively low values in all capability areas; however, with second most high value in after sales service in comparison to other clusters. Based on the ranks in Table 6, the highest values for this cluster are found in delivery speed, delivery dependability, and at the shared third place, conformance quality and the ability to introduce new products. This is the smallest cluster, with 14 cases. Similarly to Frohlich and Dixon (2001), this cluster is at this point named “idlers”.

In contrast, cluster 2 appears to have an overall broad emphasis of capabilities, with most of the highest values in comparison to other clusters: ability to make rapid product changes and introduce new products and services (the latter with a clear difference to the others), volume flexibility, conformance quality, and after sales service. The top three capabilities for this cluster are delivery dependability, conformance quality and volume flexibility. This is the largest cluster with 92 cases. As this cluster appears a combination of two clusters from Miller and Roth (1994), we name it as “innovator-marketeers”.

Cluster 3 has the most distinctive profile of all, with the relatively highest values in low price, broad product offering, performance quality, delivery speed and delivery dependability. Relatively lowest values are found in the ability to introduce new products and services, as well as in after sales service. This cluster is relatively small as well (21 observations), with top ranking capabilities in delivery dependability, delivery speed and low price (shared position), and conformance quality. Here we suggest calling this cluster "contract manufacturers".

Cluster 4 is mostly in the middle of 1 and 2, however, with the relatively lowest value in broad product line. This cluster puts the second highest emphasis on developing new products and services. The highest ranking values are found in conformance quality, volume flexibility and delivery dependability. This is a relatively large cluster (53 observations). Here we choose to use the term "niche-marketeers" for this cluster.

We further validate the four-cluster solution by examining the predictive power of the cluster membership variable in terms of selected background variables. Table 7 presents cluster means by the background variables, giving also further insight in terms of the cluster profiles.

Table 7. Four-cluster solution criterion validity assessment through background variables

Variables (background)	Cluster no.	Cluster mean (*)	F	Sig.
TURNOVER	1	14.2 MEUR	0.225	0.879
	2	13.5 MEUR		
	3	11.4 MEUR		
	4	13.1 MEUR		
CHANGESPEED	1	4.29	1.659	0.178
	2	4.78 (4)		
	3	4.62		
	4	4.32 (2)		
CHANGEUNPREDICT	1	4.64	0.485	0.693
	2	4.62		
	3	4.57		
	4	4.36		
HIGHTEC	1	3.86	3.177	0.025
	2	4.57 (3)		
	3	3.38 (2)		
	4	4.19		
PRODUCTDEV	1	4.79	6.332	0.000
	2	5.47 (3)		
	3	4.00 (2, 4)		
	4	4.98 (3)		
PROCESSDEV	1	4.57 (2)	3.075	0.029
	2	5.42 (1, 4)		
	3	5.19		
	4	4.91 (2)		
PERSPECTIVES	1	4.21	2.247	0.085
	2	4.91 (3)		
	3	4.14 (2)		
	4	4.81		

* Statistically different to cluster no. X, at 0.05 level

Here we observe cluster 2 suffering the most from rapidly changing markets, especially in comparison to cluster 4. Cluster 2 is also significantly more "high-technology" oriented in comparison to cluster 3, with most investments into new product development, especially in comparison to cluster 3. Cluster 2 also appears to have the most positive business perspectives in comparison to the other clusters, and especially in contrast to cluster 3.

Examining dominant industry affiliations in each of the clusters, reveals high frequency for the following industries: machinery/appliances, computers/electronics and metal products in cluster 2, whereas the dominant industry in cluster 3 is metal refining and metal products, i.e. relatively more upstream in the machine building value chain (a dominant industry in Finland and in the sample). This supports our choice for the name for this cluster (contract manufacturers). Cluster 4 is also dominated by metal refining and metal products, as well as machinery and appliances.

5.2 Comparison of cluster solution with extant research

Similarly to Zhao et al. (2006), we compare our cluster result with those of Miller and Roth (1994), Frohlich and Dixon (2001) and Zhao et al. (2006). The comparison is conducted by evaluating correlation of capability rankings in clusters, with the Spearman's rank order correlation coefficient. For the purposes of comparability, we average the two dimensions of design flexibility (i.e. ability to make rapid changes to products and services, and the ability to introduce new products and services) into a combined design flexibility taxon, and use a resulting revised ranking in the comparisons. We also used the original cluster means of Miller and Roth (1994) to create a revised ranking without advertising and broad distribution.

Statistically significant rank correlations are only observed between the contract manufacturer cluster (3) of this study and the Caretakers and Marketeers clusters of Miller and Roth (1994), with correlation coefficients of 0.790 and 0.695, respectively. We choose Caretakers for further analysis, and show mean-based profiles in Figure 4 (both measured in 1-to-7 point Likert scale).

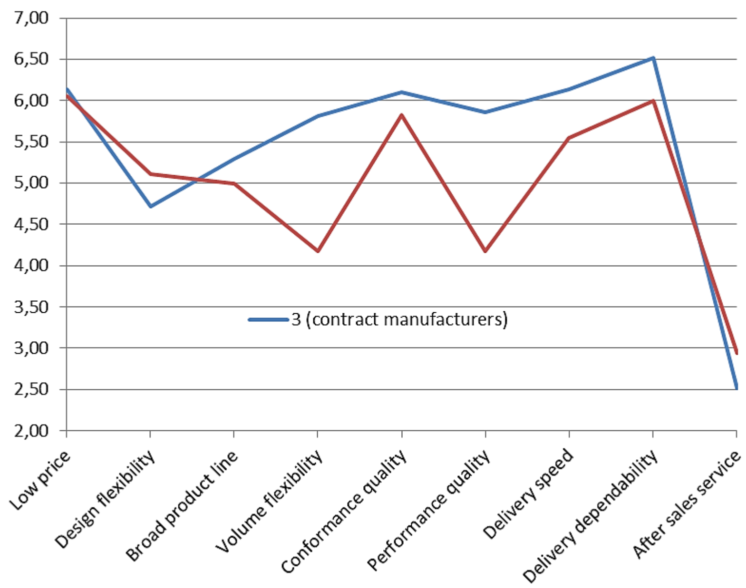

Figure 4. Comparison of the Caretaker cluster with Contract manufacturer cluster

In comparison to the Caretaker cluster of Miller and Roth (1994), the contract-manufacturer cluster of this study places less emphasis on design flexibility and after sales service, and much more emphasis on volume flexibility and performance quality.

Although the statistical analysis does not produce significant result that would suggest evidence on finding any of the clusters of previous research in our sample, some similarities between the cluster profile descriptions can perhaps be identified. Our cluster 1, coined as "idlers", appears similar to Caretakers of Roth and Miller (1994) in a sense that both emphasise time-based competition and conformance quality. However, our cluster does not focus on low price as a competitive capability. Similarly to Frohlich and Dixon's (2001) idlers, and low emphasisers of Zhao et al. (2006), cases in this cluster "reported very little emphasis on any of the competitive capabilities" (Frohlich and Dixon, 2001), although priorities were different. In order to differentiate our cluster form the one of Frohlich and Dixon (2001), we can rename our cluster "time-focused idlers".

As stated earlier, cluster 2 appears to have an overall broad emphasis of capabilities (similarly to the Mass Servers of Zhao et al. 2006), with most of the highest values in comparison to other clusters. These were found the following taxons: ability to make rapid product changes and introduce new products and services (the latter with a clear difference to the others), volume flexibility, conformance quality, and after sales service. The top three capabilities for this cluster are delivery dependability, conformance quality and volume flexibility. Essentially, this cluster appears to combine marketable manufacturing process capability with product innovation, bringing together the two clusters of Miller and Roth (1994). Low price is not overly emphasized; however, it appears to be on the agenda.

Our cluster 3 (contract manufacturers) appears very similar to the cluster introduced by Zhao et al. (2006, 630): "… speed, cost and … quality were the most strongly emphasized capabilities in this cluster. … this cluster appeared to avoid … introducing new products." In terms of differences, our contract manufacturers emphasize more broad product line, thus we avoid the term specialized. Also volume flexibility is emphasized more, a desirable trait for a contract manufacturer that also does not provide after sales services on behalf of the OEM customer.

Cluster 4, coined as niche-marketeers, demonstrates the lowest emphasis on broad product line, with simultaneous relatively high emphasis on developing new products and services, suggesting a niche player. Similarly to the marketeers of Miller and Roth (1994), this cluster emphasizes conformance quality, volume flexibility and delivery dependability (marketable process capability); however, the narrow product line is in strong contrast with broader orientation of the original marketeers cluster. Similarities include also some emphasis on price; however, after sales service is not strongly on agenda. In comparison to Zhao et al. (2006) quality customizers, niche-marketeers place somewhat less emphasis on speed and performance quality, whereas narrow product line is again a differentiating factor.

In summary, our results suggest some alignment with the results of previous research, in addition to significant differences that suggest the role of context in the evolution of manufacturing strategies. While similarities were found with the basic taxonomy of Miller and Roth (1994), perhaps surprisingly, there were many similarities with China-based findings of Zhao et al. (2006) as well.

6. Discussion and conclusions

This research illustrated that clustering applied to our empirical data arising from Finland. This particular country is having long history of large corporation dominance, and SME sector has received not that much research, and this is particularly the case of industrial sector. More understanding is needed before appropriate actions could be completed to support SME companies. There is clear and immediate need for this as large corporations seem to continue to restructure and gradual job loss is fact among industrial companies. SMEs are the only remedy for this dire situation – as illustrated export and revenue growth has been present in some industrial sub-sectors after crisis of 2008-2009, namely in optical and medical equipment as well as fuels and oils. These sectors offer good opportunities for product supply of metal and electronics SMEs, but also in large-scale investment project supplying initial and innovative machinery (which could be later on supplied around the world as technology diffusion proceeds further).

The identified four clusters had similarities with earlier research, but also considerable differences. Major difference to earlier studies is the low importance of after sales services among respondents (or more generally, servitization). Currently after sales is one of the most important sources of revenue, and especially profits, among large corporations (together with finance). However, SMEs do not even identify this as an important. It could be so that among Finnish SMEs products are supplied through OEM brands, and after sales service is in hands of others. Change in attitude and service willingness of course takes time, but there is clearly opportunity for companies to gain considerable additional income in the future as their offered products mature and supplied population grows. Similarly as what is currently the case with innovation, revolution is in need with after sales services, and networked approach and collaboration between companies is the only solution to gain foothold in here.

Based on this research also operations strategy process needs refining among respondents. Clusters 1 and 2 illustrate this need very clearly. In the former all variables have low importance (except delivery speed and possibly after sales), whereas in the latter everything is important (possibly broad product line and after sales being less important). Strategy is always about tradeoffs, i.e. priority is given to some while partly neglecting other capabilities. In these cases, one may ask, is there actually an operations strategy at all? Changes do not need to be tremendous here, but starting strategy oriented university-industry dialogue e.g. through practitioner oriented expert articles or by showing best practice examples from abroad could act as such catalysts for improving SME strategizing. Shaping and sharpening strategy further is clearly needed in the Finnish manufacturing SME sector.

In terms of theoretical contribution, our study suggests possible significant differences between the manufacturing strategy taxonomies describing large firms and SMEs. In some ways, our taxonomy was more in line with the Chinese results (which included more SMEs) than with the studies focusing more on large firms for example from North America. Further replication studies are needed for refinement of the SME taxonomy, and possibly taking into account value chain positions etc. Further research should aim to also link clusters with operational and financial performance.

We also suggest replication of the study in other settings, such as in proximate three Baltic States and St. Petersburg area of Russia, but also in other European countries, with focus firmly remaining in SMEs. This would further contribute to the refinement of theory on manufacturing strategy taxonomies, as well as policy making in this crucially important area.

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Environmental Sustainability in the UK and Indian Aerospace Industries: A comparative Study

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This paper focuses on exploring the contrasting structures and dynamics of the UK and India Aerospace Industrial Systems. It also presents assessment of the environmental sustainability in the two industrial systems. This paper brings together fragmented literature from multiple sources, industry reports, and data from key actors in the two countries. Where before, literature on the structure of the UK and Indian aerospace industrial systems were fragmented, this paper attempts to produce an up-to-date model of the current structure of the UK and Indian Aerospace industrial systems. Research approach includes an examination of relevant literature and industry reports to inform a set of "basic" industrial system maps involving structure. Semi-structure questionnaire is developed data collection involving policy makers, key industrial actors, research institutions and regulatory bodies. With-in-Case and Cross-Case analysis approach is used in order to identify key dynamics and environmental challenges for the two industries.

NB: the full paper will be available online following the symposium.

18th Cambridge Symposium on International Manufacturing

Systems thinking capability essential for transformation towards sustainable industrial system

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Abstract

Organisations are exploring new sustainable business models to prepare for a fundamentally different operating environment, due to the emergence of increasingly complex problems, combined with growing concerns for the environment. Organisations currently lack understanding of possible futures and where to focus efforts to inform planning. There is a need to develop the know-how to enable changes across the whole industrial system and to identify system-wide opportunities. The paper explores the research question; What is the role of systems thinking in designing a sustainable industrial system? The paper reports the results of exploratory case studies observed through document analysis and interviews. Evidence from the case studies illustrate organisations that are able to work across the firm boundaries are found to be able to deliver radical innovation. Organisations that are willing to experiment by working with unusual partners and widen the system boundaries are found to be able to create new forms of value.

Keywords: systems thinking, whole system design, Industrial sustainability

1.0 Introduction

In the period up to 2050, interactions between manufacturing and the natural environment will be subject to a number of powerful changes. Growing global populations will raise demand for resources, particularly as they become wealthier. Climate change is likely to increase the vulnerability of global supply chains. Consumers will call for products that meet higher environmental standards, and governments may increase their use of environmental regulations (Foresight, 2013). Figure 1. Illustrates the environmental trends most likely to converge, leading to manufacturing activities becoming more sustainable and resilient.

It is stated that manufacturers will therefore need to strive for greater efficiency in their use of materials and energy, which will provide resilience to the resulting volatility in the price and availability of resources. Manufacturers will also need to explore new ways of doing business, for example by expanding into 're-manufacturing' of end of life products, or by producing increasingly robust products for 'collaborative' consumption by consumers. We argue that Industrial Sustainability will not be achieved simply by new technology: the configuration of the industrial system will need to change dramatically, introducing new concepts such as cradle-to-cradle (Braungart and McDonough, 2009, Braungart et al., 2007), slow manufacturing, local manufacturing (Piore and Sabel, 1984, Kumar, 2004) and challenging today's business models (e.g. Chesbrough, 2007, Comes and Berniker, 2008, Nidumolu et al., 2009, Lee and Casalegno, 2010). Society must also play a role (Huppes and Ishikawa, 2010), as we explore new forms of value. Following on from eco-efficiency and eco-factory programmes, those organisations, which seek to lead in this field, are already beginning to explore what the new shapes of the industrial system may be (WBCSD, 2010). There is a need to develop the know-how to enable changes across the whole industrial system and to identify system-wide opportunities.

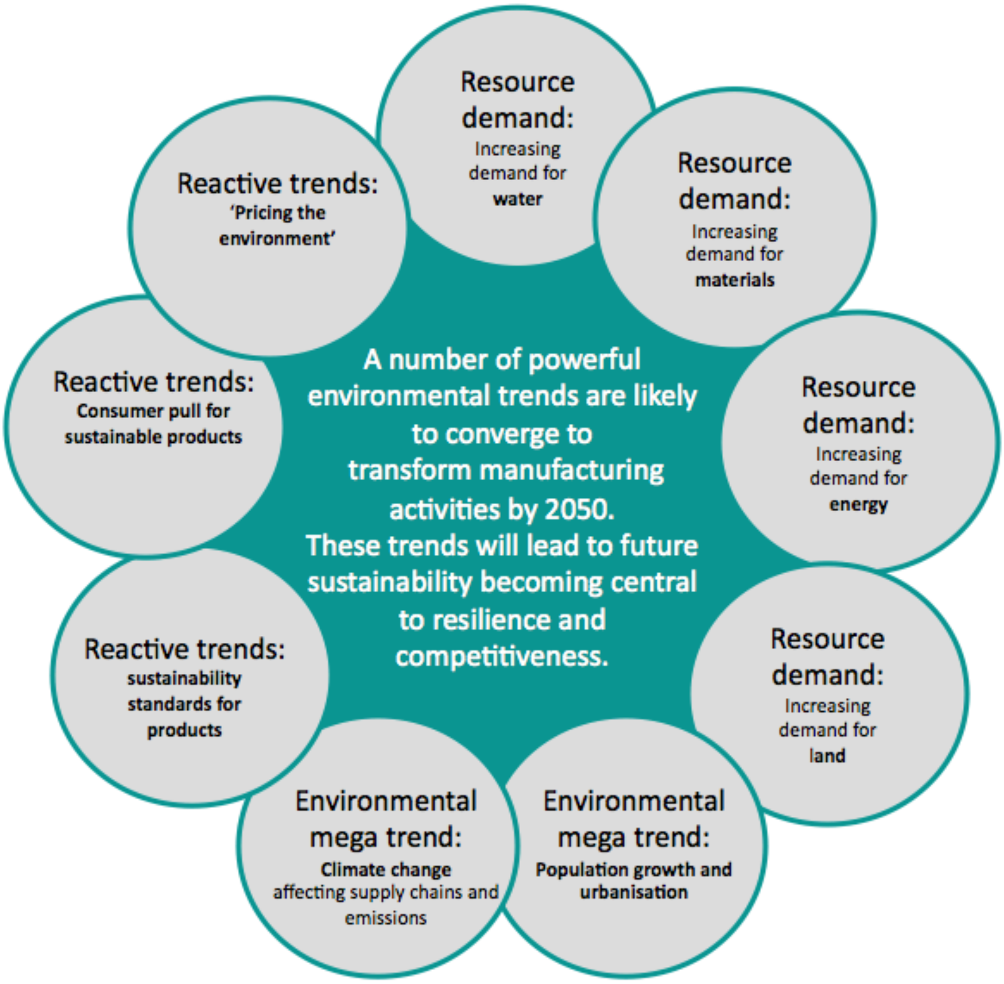

Figure 1. Environmental trends most likely to converge, leading to manufacturing activities becoming more sustainable and resilient. Source: adopted form (Foresight, 2013)

1.1 Aims and objectives

The aim of the research is to better understand the role of systems thinking in designing a sustainable industrial system.

1.2 Research question

The greatest opportunity to reduce the environmental impact of an industrial system comes about when we consider the system as a whole, because the optimisation of any one part is ultimately constrained by other aspects. Efficiently manufacturing products that are inefficient in use, for example, is not enough. This approach can even result in substantially negative outcomes when efficiency gains or cost reductions result in increases in consumption, the so-called rebound effect. It appears that creating opportunities to work across firm boundaries could unlock and trigger system innovation and value for all parties and for society as a whole. The research will investigate the knowledge gap; what is the role of systems thinking in designing a sustainable industrial system? The research will specifically investigate; how the firms' ability to co-ordinate and work outside its system boundaries has improved the sustainability related performance.

2.0 Research method

Figure 2 illustrates the research method used;

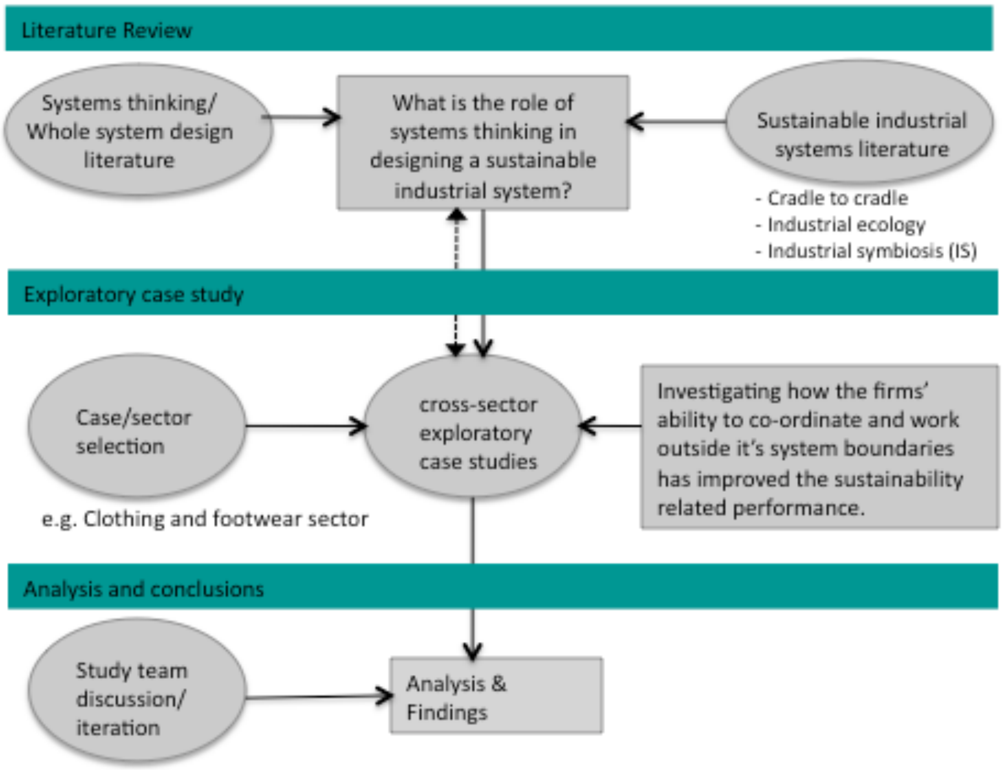

Figure 2. Research method

The research domains of system thinking, whole system design and sustainable industrial systems are reviewed to provide an understanding of pioneering author's contributions and discussions to understanding the research focus. This research is exploratory in nature, involving understanding; what is the role of systems thinking in designing a sustainable industrial system? And investigating, how the firms' ability to co-ordinate and work outside its system boundaries has improved the sustainability related performance through the case study. The use of multiple data collection methods (interviews, document analysis) within the research methods assisted with triangulation of data, thereby strengthening the largely qualitative outcomes of the research. Moreover, it supported the reliability and validity of the findings. The applied data collection tools include semi-structured interviews with open questions and documentation reviews. The interview template takes the form of a questionnaire, interviews were conducted with a cross-functional group of senior management respondents of the focal firms, including senior management and environmental lead roles. The semi-structured interviews were conducted with the aim of gaining comparable views of competing company sustainability strategies. All interview notes were sent immediately for comment, with further analysis fed back to participants. The approach was set up to ensure that there is both a discussion and consistent output across the case study firm. Finally, the data set was further reviewed against secondary data from published reports. The epistemological positioning of the research and case study protocol used in this research meet the validity strategies suggested by Creswell and Miller (2000) including triangulation, member checking and the audit trail.

The case study chosen had unique business strategies, were companies that have widened their system boundaries. And companies that were experimenting by working with unusual partners to create value. In addition, data availability and accessibility were determinant factors in the case selection process

3.0 Literature review

The following bodies of the literature are considered pertinent to the aim of this article:

- System thinking
- Whole system design
- Industrial sustainability

3.1 System thinking

Seiffert and Loch (2005) suggest that the most important property of systems is that they are made up of several parts that are not isolated, but closely interlinked, forming a complex structure. Systemic or systems thinking, facilitates the improved understanding of these complex systems and enables the identification and utilisation of interrelationships and linkages as opposed to things.

Systems thinking is a technique for investigating entire systems, seeking to understand the relationships, the interactions, and the boundaries between parts of a system (Senge, 2006). Systems thinking is particularly well suited to modeling highly complex open-systems where an integrated understanding is required at both the micro and macro-levels in order to predict or manage change. This contrasts with the dominant analytical approach of the physical sciences, which is based on reductionism, analysing closed-systems at the level of their constituent parts and then simplifying to draw out general conclusions. Systems thinking is a generic term that spans a range of more than 20 tools and methodologies (Reynolds & Holwell 2010). An initial survey (table 1 - Systems thinking methods for sustainability research) indicates three key methodologies that seem most relevant to investigating Sustainability.

Table 1. Systems thinking methods for sustainability research

Approach	Thinking process	Tools & Techniques
Soft Systems	Conceptual models, divergent sequence of cause and effect	Diagnosis through rich pictures, root definitions, conceptual models, and performance measures
System Dynamics	Dynamics feedback loops, stocks and flows	Business simulations models
Critical systems Heuristics	Understanding multiple values, perceptions and beliefs	Diagnosis through reflective practice, boundary critique, ideal vs. actual mapping, selectivity.

Source: adopted from (Reynolds & Holwell 2010).

Senge (2008) proposes 3 core learning capabilities; seeing systems, collaborating across boundaries and creating desired futures for systemic change. The author argues that these capabilities are needed for creating regenerative organisations, industries and economies and states and that if you take away one the whole fails. The authors agrees with this view that without the capacity to see systems and their place in them, people and organisations will naturally focus on optimising their piece of the puzzle rather than building shared understanding and a larger vision. Senge (1990) explains that 'systems thinking' is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots. It appears that system thinking is a way of approaching problems: rather than applying a strict linear methodology, the techniques are iterative, and designed to stimulate investigation, discussion and debate by encouraging multiple perspectives. Systems-thinking does not aim to provide quantifiable answers to specific problems, but rather provides a range of options and better understanding of the implications of those options (Meadows & Wright 2009).

3.2 Whole system design

RMI (2006) define whole system design as *'optimising not just parts but the entire system ... it takes ingenuity, intuition, and teamwork. Everything must be considered simultaneously and analysed to reveal mutually advantageous interactions (synergies) as well as undesirable ones'*. Whole-systems thinkers see wholes instead of parts, interrelationships and patterns, rather than individual things and static snapshots. They seek solutions that simultaneously address multiple problems (Anarow et al., 2003). Lovins and Cranmer (2004) are among the small number of authors who suggest that understanding the dynamics of a system is integral to the whole system approach. The Rocky Mountain Institute (2004) highlights systems thinking as the method that should be utilised not only to point the way to solutions to particular resource problems, but also to reveal interconnections between problems, which often permits one solution to be leveraged to create many more.

Meadows (1997) lists nine places to intervene in a system, in increasing order of impact: numbers (subsidies, taxes, standards), material stocks and flows, regulating negative feedback loops, driving positive feedback loops, information flows, the rules of the system (incentives, punishment, constraints), the power of self-organisation, the goals of the system, and the mindset or paradigm out of which the goals, rules, and feedback structures arise.

"Whole-systems thinkers see wholes instead of parts, interrelationships and patterns, rather than individual things and static snapshots. They seek solutions that simultaneously address multiple problems" (Anarow et al., 2003). It appears it is necessary to develop the skills to understand what a system is and where the system boundary should be drawn. It is understood that there are multiple factors that influence the success of a whole system design process; identification of relationships between parts of a system to ultimately optimise the whole, and the need for actors involved in the process to develop trans-disciplinary skills and the dynamics of a flattened hierarchy, ability to think holistically and to view the bigger picture.

A whole system design approach encourages those involved to regard a problem as a whole system and not just to concentrate on one particular component of that system. Additionally, it recognises that a problem is created by every part of the system in which the problem is embedded, and that the problem can and should be addressed at every level. When developing a solution the same forces exist and it should be recognised that interventions within a specific location will impact throughout the system; this requires understanding and management. Anarow *et al.,* (2003) recognise that the approach focuses on interactions between the elements of a system as a way to understand and change the system itself. Whole-systems thinking pays close attention to incentives and feedback loops within a system as ways to change how a system behaves (Senge, 1990). Without this whole system perspective crucial impacts between components could be missed, therefore disrupting the system as a whole.

3.3 Industrial sustainability

Authors such as Ehrenfeld (2009), Graedel & Allenby (1996), McDonough & Braungart (2002), Robèrt & Lovins (2002) and Senge (2008) have proposed a variety of mental models and frameworks that contribute to understanding what sustainability is. Some selected concepts such as cradle to cradle, industrial ecology and industrial symbiosis are explored in this section.

3.3.1 Industrial Ecology

Ecosystems are properly termed "systems" in part because energy and materials flow between and among trophic levels" (Graedel, 1996). Industrial Ecology (IE) is a metaphor for how industry can learn from observations about how species interact and materials flow within natural ecosystems and at the higher system level the biosphere (Frosch and Gallopoulous, 1989; Ayres, 1989; Scolow et al., 1994; Clift, 1997; Deutz and Gibb, 2008; Ehrenfield, 2008). Its aim is to align industrial processes with 'material flows in living systems' (Ehrenfield, 2008) through the reorganisation of firms into 'industrial ecosystems' (Deutz and Gibb, 2008). Thomas et al (2003) highlights the three specific dimensions of the industrial ecology metaphor put forward by both (Frosch and (Gallopoulous, 1989) and (Ayres, 1989) as; the optimisation of energy and materials within an industrial system; the minimisation of waste and the exchange of by-products from one production process as an input in another (Thomas et al., 2003).

The key concepts that emerge from industrial ecology is the idea of the waste or the output of one organism in nature being the input or food for another organism namely the idea of 'waste equals food'. However, Braungart et al. (2007) also emphasises the fact that the concept of waste does not even exist in nature at all. The idea of designing out waste goes beyond the concept of de-materialization – merely doing more from less material input (Braungart et al., 2007) to designing out aspects of products or industrial processes that produce outputs that cannot be cycled and re-used safely in the techno sphere (Robért et al.; 2004) as technical nutrients or enter the biosphere as biological nutrients (Braungart et al., 2007).

3.3.2 Cradle to cradle model

(McDonough & Braungart, 2002) proposed a cradle-to-cradle model as a specific form of industrial ecology, whereby they separate all materials into either 'biological nutrients' or 'technical nutrients'. Biological nutrients can be decomposed and allowed to re-enter the natural system. While technical nutrients should be kept within the industrial system and used multiple times.

3.3.3 Industrial symbiosis (IS)

Refers to a 'place-based approach' to industrial ecology whereby firms operating within a specific geographical location exchange by-products (Deutz and Gibb, 2008). One of the most famous and most commonly referred to examples of industrial symbiosis is Kalundborg in

Denmark. Eco-Industrial Parks (EIP) are attempts to apply lessons from Kalundborg to other industries and contexts and extends the metaphor of 'exchanging of materials' to 'sharing resources' including both physical materials but also information and infrastructure (Deutz and Gibb, 2008). However it is acknowledged that creating geographically located complexes where industry actors exchange waste is more complex than it sounds in theory and also designing industry ecosystems based on waste exchange potentially leads to the lock-in of certain practices that produce waste instead of designing out the waste in the first place (Oldenburg and Geiser, 1997).

From the Industrial sustainability concepts reviewed, it is found that the concepts such as industrial ecology and cradle-to-cradle provide sets of design rules that contributes towards learning from the characteristics of natural systems (Ehrenfeld 1997, Benyus 2002). It is understood as essential to look at the entire system of designing, making and serving to achieve the level of environmental performance change that is needed, thus it is essential to think as whole rather than optimising individual systems units (Figure 3). The mental models help reflect the need for 'closed loop' cycles for components and materials (where materials are not lost to the system), and trigger thoughts on networked-distributed production, system resilience and learning from biological examples.

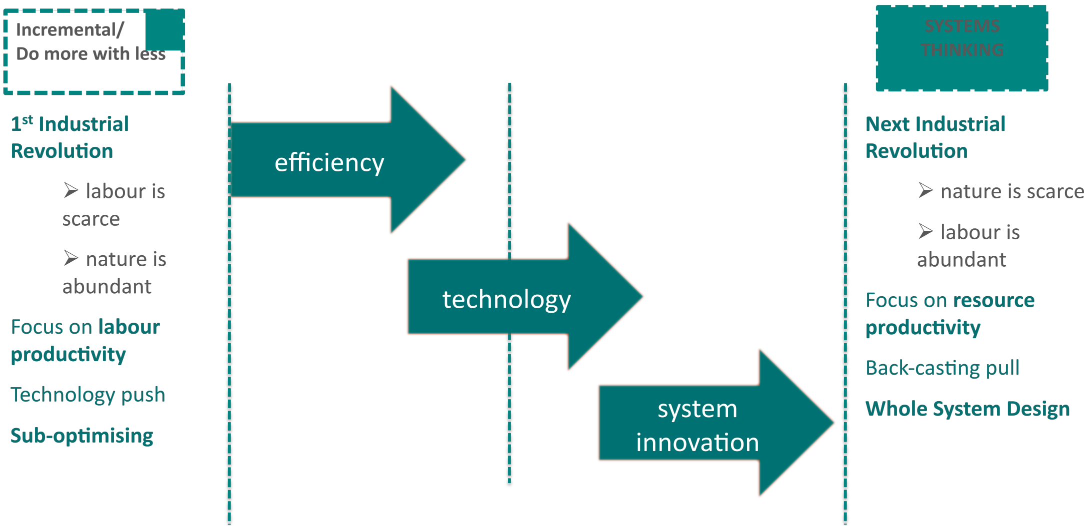

Figure 3. Proposed transformation pathway

In the first industrial revolution it can be argued that the challenge was that labour was scarce and material were abundant, drawing the focus of management onto labour productivity through automation and other practices. The rather profligate and linear business model of make- produce-sell-use and more often than not throwaway has been economically successful, but is argued to be at the root cause of some of the challenges industry is faced with today. Then labour was the limiting factor of production. But now, there is perhaps a surplus of people, while natural capital (natural resources) and the ecological system that supports industrial activity is increasing under threat from a sustainability perspective. Figure 3 illustrates the proposed transformation pathway to a sustainable industrial system.

4.0 Case study findings

This section discusses the findings from exploratory case studies and interviews of firms' who have been able to co-ordinate and work outside its system boundaries to improve the sustainability related performance.

Case A- (Nike)

A reputed global apparel and footwear company, has realised its business model based on abundant raw materials, cheap labour and endless consumption, will not sustain it in the long term. Challenges such as resource scarcity and climate change, alongside greater transparency and customer demands, are creating an unprecedented era of risk and volatility. In a business that contracts to around 900 factories directly and uses a palette of more than 16,000 materials, that volatility has the potential to disrupt its business. Nike is found to be taking actions to transforms the systems in which they are operating (Nike, 2014).

Cross industry partnerships (widening the system); Nike partnered with IKEA a furniture company to invest in Dyecoo, waterless dying technology. This is an example of, new forms of collaboration with unusual partners. Which enables new innovations and disruptive technologies to scale. DyeCoo's technology eliminates the use of water in the textile dyeing process. This technology appears to have the potential to revolutionize textile manufacturing. Conventional textile dyeing requires substantial amounts of water. On average, an estimated 100-150 liters of water is needed to process one kg of textile materials today. Industry analysts estimate that more than 39 million tonnes of polyester will be dyed annually by 2015 (Nike, 2014). Nike states it expects DyeCoo's supercritical fluid carbon dioxide, or "SCF" CO2 dyeing technology, to have a particularly positive impact in Asia, where much of the world's textile dyeing occurs. As this technology is brought to scale, large amounts of water used in conventional textile dyeing will no longer be needed, nor will the commensurate use of fossil fuel-generated energy be required to heat such large sums of water. The removal of water from the textile dyeing process also eliminates the risk of effluent discharge, a known environmental hazard. The CO2 used in DyeCo's dyeing process is also reclaimed and reused (Nike, 2014).

This case study is an example of finding advantageous connections across the system and new forms of collaboration outside of sector with new types of partners to create value. The case study illustrates the potential to scale technologies by partnering with unusual partners by widening the system boundary.

Case B- (Sustainable apparel coalition (SAC))

The SAC represents more than one-third of the global apparel and footwear industries. It was founded by a group of sustainability leaders from global apparel and footwear companies who recognized that addressing the industry's current social and environmental challenges are both a business imperative and an opportunity. Through multi-stakeholder engagement, the Coalition seeks to lead the industry toward a shared vision of sustainability built upon a common approach for measuring and evaluating apparel and footwear product sustainability performance (Higg Index) that will spotlight priorities for action and opportunities for technological innovation (SAC, 2014).

It is found the coalition is able to drive efficiencies across the industry. The Higg Index is able to measure sustainability performance across the supply chain, the monitoring of scores and sharing best practices is found to help companies achieve efficiencies in energy, materials, and water use through the use of the Higg index. It is also found the SAC is able to encourage continuous improvement by benchmarking facility performance against peers. Sharing best practices with other industry leaders, and collaborating on industry-wide projects is found to accelerate innovation in practices and technology. The enabler is the 'pre-competitive collaboration' platform that the SAC is able to create for system actors to work together. By pooling resources the Coalition is able to address systemic issues that individual companies can't address on their own. It is found in a highly fragmented industry, pooling customer demand for improvements will accelerate change.

This case study illustrates pre-competitive collaboration and common language as being essential elements the SAC is able to provide to transform the system to a sustainable industrial system. The system wide boundary and strategy allows companies to address systemic issues that individual companies can't address on their own, for example by collectively sharing Higg scores and sharing best practices. The individual companies are able to minimize the volume and chemical constituents of water discharges associated with manufacturing of apparel products and eliminate impacts to local communities as a system. The case study shows significant change is possible if we work to solve complex sustainability challenges together and widen the system boundary.

Case C – Brandix India apparel city (BIAC)

BIAC is a unique city based on an integrated apparel supply chain for fabrics, threads, buttons and hangers, which is being developed in Visakhapatnam, Andhra Pradesh, India. A 'Fibre to Store' concept has been created by sitting a vertically integrated value chain in one location, which included R&D and branding activities. BIAC offers the convenience of an industrial city with modern infrastructure including 'plug and play' facilities for immediate production. All business partners are provided with rapid access to facilities to meet all their requirements from sourcing to transportation. Greater efficiency in distribution is ensured through the single location of all value chain partners and a centralised logistics unit (Brandix, 2014).

BIAC is an example of a textile manufacturer that has through planned placement of operating units 'enabled real time connectivity and seamless integration of all its supply chain actors'. They operate an industrial park located in one of the biggest apparel hubs in the world offering close proximity to cost effective labor, raw materials and resources. The 'Fiber-to-Store' concept brings together the entire end-to-end supply chain in one location, the case company illustrates high maturity in co-ordination and collaboration. The company was able to do setup the industrial park by working in partnership with its suppliers and policy makers in collaboration to make its vision a reality.

6.0 Discussion

From the Industrial sustainability concepts and frameworks review it is found that the concepts such as industrial ecology and cradle-to-cradle provide sets of design rules that contributes towards learning from the characteristics of natural systems (Ehrenfeld 1997, Benyus 2002). From the system analysis review it is found that whole system thinking is argued to require three abilities: to see wholes instead of parts, to find interrelationships and to find patterns, rather than individual things and static snapshots. There is a need to understand how to collaborate and co-ordinate between organisations and across sectors at system level. It is understood creating opportunities to work across firm boundaries could unlock and trigger system innovation and value for all parties and for society as a whole. Systems thinking approach appears to be an essential capability for transformation to sustainable industrial systems. The evidence we have seen from case studies shows that sub-system approaches can dramatically improve sustainability. But to help future generations meet the needs of humanity within the carrying capacity of the planet it will be important to develop the know-how to enable changes across the whole industrial system. From the case study analysis, it was observed that systems thinking provides the foundation for a proactive approach to the design of industrial systems. Senge (2008) proposes that core learning capabilities are essential and must be developed together and argues people do not learn how to develop the collective systems intelligence to tackle complex problems if not. Without the capacity to see systems and their place in them, people and organisations will naturally focus on optimising their piece of the puzzle rather than building shared understanding and a larger vision.

It is found from Case study A, a company is able to find advantageous connections across the system by collaborating with new types of partners outside of sector with to create value. The case study illustrates the potential to scale technologies by partnering with unusual partners by widening the system boundary. It is found by experimenting and creating opportunities to work across firm boundaries allows truly radical innovation to happen, and creates value for all parties and for society as a whole. The partnership is an example of new forms of collaboration with unusual partners. Which enables new innovations and disruptive technologies to scale such as the waterless dying.

Case study B, found that ‘pre-competitive collaboration’ and ‘common language’ are essential elements to transform the system to a sustainable industrial system. It was observed that the system wide boundary and strategy of the coalition was found to allow companies to address systemic issues that individual companies can’t address on their own.

From case study C, it is observed that extensive management effort has been focused on the co-ordination dimensions in the planning process. The authors observed that during the design of the industrial park, which offers an end-to-end fiber to store concept, much extra effort went into the co-ordination efforts between the factories, such as sharing resource for water treatment, the planned placement of the operating units has enabled high productivity, improved communication and facilitates greater interaction between factories leading to value creation and partnerships. The park is planned to eventually offer an integrated ERP system to improve co-ordination among all members in the park. The case study provides insight into the management effort used to improve co-ordination of the supply chain across organizational boundaries. It is found the end-to-end configuration of the park and shared vision, allows new forms of collaboration and coordination resulting in win-win situations.

7.0 Conclusions

Evidence from the case studies illustrate organisations that are able to work across the firm boundaries are found to be able to be radically innovate. Organisations that are willing to experiment by working with unusual partners and widen the system boundaries are found to be able to create new forms of value. The system thinking approach appears to encourage partnerships between actors from outside the sector and a firms’ boundary. It is found organisations that are willing to change the business model, work with others outside it boundary are able to create new forms of value. It is observed there is a need to understand points of best leverage to prioritizing intervention. It is found that ‘pre-competitive collaboration’ and ‘common language’ are essential elements to transform the system to a sustainable industrial system from case study B. The system wide boundary and strategy of the coalition was found to allow companies to address systemic issues that individual companies can’t address on their own. From the case study analysis it is found significant change is possible if we work to solve complex sustainability challenges together and widen the system boundary.

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Developing sustainability in global value chains: the role of production subsidiaries

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Abstract

This paper explores the effect for a plant of being part of multinational network on the development of sustainable management (SM) initiatives. In particular, we hypothesize that a plant will adopt SM to a larger extent when the level of autonomy, internal and supplier integration are higher. We test such hypotheses by means of the 2014 preliminary release of the International Manufacturing Strategy Survey (IMSS). The results show that autonomy does not play a relevant role. On the other side internal and supplier integration have a positive effect on SM. All together, the results, even if preliminary, provide an interesting contribution for both research and practice.

Keywords: sustainable management, international manufacturing networks, IMSS

Introduction

With the development of global value chains, offshoring the production abroad has become a common practice for multinational companies (MNCs) willing to take the opportunity of localization advantages in other countries. Several authors and associations (Buckley & Casson, 1976; Dunning, 1998; Roza, Van den Bosch, & Volberda, 2011; UNCTAD, 2010) classify these localization advantages into: market-related factors, resource-related factors, efficiency seeking, quality of business environment and other motivations (e.g. follow the leader). This brought over time to the creation of manufacturing networks - nested in the global value chains - where every plant may have a specific degree of autonomy (i.e., at a specific localization advantage corresponds a necessary level of competence and responsibility), a certain level of integration with other plants within the network, and a specific level of integration with suppliers operating along the supply chain.

In recent years, MNCs based in developed and developing economies have continued their expansion in foreign countries. Due to this development, they are considered the backbone of the world economy. Large corporations and their supply chains account for some 80 per cent of global trade with an increasing impact on value added, jobs and income (UNCTAD, 2013). This global footprint is, however, not only economic, but affects also the society and the natural environment, as already noted in the past (e.g., Gladwin, 1987)

As a consequence, MNCs started to face growing pressures from internal and external stakeholder for the development of sustainable management (SM) initiatives (Bansal & Roth, 2000; Haugh & Talwar, 2010). These initiatives include internal and external practices a MNC adopts to lower environmental and social risks and impacts, while raising the ecological efficiency and social responsibility in its networks (Seuring & Müller, 2008; Zhu, Sarkis, & Geng, 2005).

In this process of development, MNCs can be more effective than other companies in spreading best practices and knowledge related to sustainability worldwide, as in the past with agile manufacturing, lean production and business process reengineering (Gunasekaran & Spalanzani, 2012). On the other hand, MNCs can face higher obstacles when addressing sustainability (e.g., apply global standards within local operating environments; path dependency in network design; presence of global and local stakeholders) (Chen, Newburry, & Park, 2009; Gladwin, 1987; Hall & Vredenburg, 2003; Korten, 2001; Park & Vanhonacker, 2007; Sharma & Henriques, 2005). Therefore, in this paper we want to focus on the role of path dependencies related to autonomy, network integration and supplier integration play in the process through which sustainability pressures at the MNC's headquarter translate into sustainable management initiatives at the plant level.

Literature review and hypotheses development

In the last years, the attention of external stakeholders over the multinational companies' activities has risen considerably (Sharma & Henriques, 2005). Specifically, stakeholder pressure refers to requests and requirements of external stakeholders for the firm to improve its environmental and social performance (Sarkis, Gonzalez-Torre, & Adenso-Diaz, 2010). Even though stakeholders often exert their pressures and lobbying power at the headquarter level, the MNC has to implement a network-wide strategy able develop or improve SM initiatives at the plant-level. However, this transmission of sustainability pressures in the network and then in the plant's surrounding environment (supply chain) can be affected by autonomy, network integration and supplier integration.

First, autonomy refers to the decision-making power within strategic, functional and operational areas (Kawai & Strange, 2013) (O'Donnell, 2000). The higher the autonomy also the higher the competences that the plant should have to manage its processes (Ferdows, 1997). Golini et al. (Golini, Longoni, & Cagliano, 2013) already found a positive relation between site competence and the adoption of sustainability programs (both environmental and social).

Thus, we propose the following:

HP1a, b. Higher autonomy positively leads to higher adoption of a) internal and b) external SM initiatives at the plant level.

Network integration (or internal embeddedness) is a well-known concept in the international business research and it measures (Yamin & Andersson, 2011) the extent of business relationships within the network (i.e., between the headquarters and subsidiaries and between subsidiaries). In OM the same concept has been used to quantify the extent of information sharing (Rudberg & Olhager, 2003), joint decision making (Ferdows, 2006) and joint innovations (Colotla, Shi, & Gregory, 2003) in the network. Nevertheless, this concept was never put in relation with the development of SM initiatives in the networks. Our hypothesis is that the higher the degree of network integration, the more smoothly sustainability pressures are transmitted and translated into plant-level practices. We derived such hypothesis considering two elements. First, exploiting integration, corporations in the past were able to spread best practices (Kostova, 1999); second, exchange of information and collaboration is essential to develop sustainability within networks (Gualandris, Golini, & Kalchschmidt, 2014). Accordingly, we hypothesize that:

HP2. Higher network integration positively leads to higher adoption of internal SM initiatives at the plant level.

Similarly, supplier integration (or external embeddedness) could be necessary when developing external SM practices. When looking at an extended supply chain as a single system, supplier integration represents the degree a company partners with its suppliers to structure inter-organizational strategies and practices into collaborative, synchronized processes (e.g., Flynn, Huo, & Zhao, 2010; Stank, Keller, & Daugherty, 2001). Supplier integration engenders mutual trust and commitment, increases contract duration, increases the form and extent of information sharing, and increases responsiveness to competitive concerns, threats and opportunities. Conversely, as the level of integration decreases, opacity, fragmentation and transaction-based relationships governed by contracts that rely on highly competitive markets to control prices characterize the structure of the extended supply chain. Hajmohammad *et al.* (2012) demonstrate that an organisation benefits from more intense interaction with suppliers through the identification and absorption of external knowledge that can extend the capacity of a buying firm to effectively implement innovations that are beneficial for the environment. In addition, consolidated partnering policies and integration procedures are better suited to accommodate sustainability goals, fostering the adoption of external SM practices by the implementing firm (Bowen *et al.*, 2001; Vachon and Klassen, 2006). Accordingly, we state the following:

HP3. Higher supplier integration positively leads to higher adoption of external SM initiatives at the plant level.

Overall, our conceptual framework is shown by Figure 1:

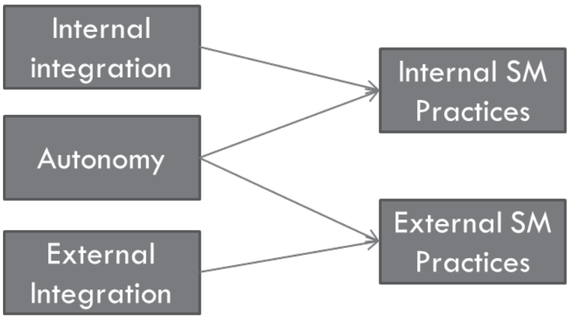

Figure 1 – Research framework

Methodology

To investigate the above research hypotheses, we used the data from the sixth edition of the International Manufacturing Strategy Survey (IMSS 6), which is still in progress.

This database is particularly suitable to our purposes as the unit of analysis of the IMSS questionnaire is the plant and we selected only those plants that belong to a multi-plant network. However, the first section of the questionnaire (dealing, among the others, with internal and external pressures) requires to provide information about the business unit level. Moreover, information about how the plant is integrated in the network is available.

The sample used in this study is described in Table 1. In particular, 465 companies (from the 843 in the preliminary release of the global database) provided information for this study (i.e., we dropped the records that did not provide information on the considered variables). To verify the absence of bias in this final selection, we performed several tests on the variables of interest (i.e., SM) between the selected and the excluded cases. No significant difference was found (i.e., p-values always higher than 0.10). The sample consisted primarily of large companies (42.80% of the sample), but medium and small companies were also well represented. Different industrial sectors from the assembly industry in different positions of the supply chain were considered.

The variables and measures are described in detail below. Additionally, a proof of the validity and reliability of our measurements is provided.

Table 1 – Descriptive statistics in terms of (a) country, (b) size, (c) industrial sector (ISIC codes)

(a)

Country	**N**	**%**
Belgium	21	4.52
Canada	10	2.15
China	65	13.98
Denmark	22	4.73
Finland	12	2.58
Germany	10	2.15
Hungary	32	6.88
India	73	15.7
Italy	27	5.81
Malaysia	14	3.01
Norway	22	4.73
Portugal	24	5.16
Romania	14	3.01
Slovenia	11	2.37

(b)

Size*	**N**	**%**
Small	171	36.77
Medium	95	20.43
Large	199	42.80
Total	**465**	**100.0**

(c)

ISIC**	**N**	**%**
25	136	29.25
26	67	14.41
27	67	14.41
28	116	24.95
29	61	13.12
30	18	3.88
Total	**465**	**100.0**

Spain	16	3.44
Sweden	27	5.81
Switzerland	17	3.66
Taiwan	20	4.3
The Netherlands	28	6.02
Total	**465**	**100.0**

* Size**:** Small: equal or less than 250 employees, Medium: 251-500 employees, Large: over 501 employees

**ISIC Code. 25: Manufacture of fabricated metal products, except machinery and equipment; 26: Manufacture of computer electronics and optical products; 27: Manufacture of electric equipment; 28: Manufacture of machinery and equipment not classified elsewhere; 29: Manufacture of motor vehicles, trailers, and semi-trailers; 30: Manufacture of other transport equipment.

Measures

As noted earlier, SM comprises a set of internal and external initiatives a plant adopts to lower environmental and social risks and impacts, while raising the ecological efficiency and social responsibility in its supply chain. In line with this definition and with measurements adopted by peers (Gualandris & Kalchschmidt, 2014), internal SM is measured by a six-item scale which captures a plant's effort spent in the last three years into implementing (SM1) Environmental certifications (e.g., EMAS or ISO 14001); (SM2) social certifications (e.g., SA8000 or OHSAS18000); (SM3) Formal sustainability oriented communication, training programs and involvement; (SM4); Energy and water consumption reduction programs (SM5) Pollution emission reduction and waste recycling programs; (SM6) Formal occupational health and safety management system.

Differently, external SM is measured by a three-item scale which captures the effort spent in the last three years into implementing (SM7) Suppliers' sustainability performance assessment through formal evaluation, monitoring and auditing using established guidelines and procedures; (SM8) Training/education in sustainability issues for suppliers' personnel and (SM9) Joint efforts with suppliers to improve their sustainability performance. Internal and external SM are calculated as the average of these items, which were measured on a five-point Likert scale, where 1 indicated "none" and 5 indicated "high." The descriptive statistics for these items are provided in the appendix (see Table A.1).

In line with existing literature, the autonomy of plant has for areas such as production, procurement/supply chain, and product/process development is captured by asking plants to indicate to what extent they (A1) can make their own strategic decisions and (A2) are autonomous in defining the production plan.

According to the literature previously cited, network integration captures the extent of business relationships within the network (i.e., between the headquarters and subsidiaries and between subsidiaries) (Yamin & Andersson, 2011). Thus, our five-item five point Likert scale measures the current level of implementation of programs related to: (NI1) information sharing with other plants within the networks; (NI2) joint decision making with other plants within the network; (NI3) joint innovation with other plants within the network; (NI4) use of technology to support communication with other plants within the network; (NI5) network performance management systems (see table A.1 in appendix).

According to the literature previously cited, supplier integration captures the degree a plant partners with its suppliers to structure inter-organizational strategies and practices into collaborative, synchronized processes (e.g., Flynn et al., 2010; Stank et al., 2001). Thus, our three-item five point Likert scale measures the effort put in the last three years into implementing (SI1) information sharing with key suppliers; (SI2) developing collaborative approaches with key suppliers and (SI3) joint decision making with key suppliers (see table A.1 in appendix)

To avoid any influence of alternative factors that were not included in our model, we added several *control variables*. First, we controlled for plant size (measured as the number of employees in the company) because it is generally considered a relevant contingent variable affecting both sustainability priorities and management (e.g., Pagell *et al.*, 2004).

The location of the plant is captured by a dummy variable equal to 1 when the plant is located in a developed country (GNI per capita > 28000).

We control for the role of external pressure, i.e. the requests and requirements that external stakeholders give to the firm to improve its environmental and social performance, in the development of sustainability initiatives at the plant level. For instance, customers increasingly ask for environmentally friendly products made respecting human rights throughout the whole supply chain; NGOs have been very active in monitoring sustainability practices; mass media always more frequently investigate labor practices at the companies or suppliers facilities; governments ask for more responsible behaviors. This led MNCs to start adopting corporate social responsibility practices that, over time, were extended to their networks (of plant and suppliers). In line with the literature (Sarkis et al., 2010), 'external pressure' is captured by a two-item five point Likert scale which measures the level of (EP1) environmental pressure (e.g. stakeholders call for environmentally friendly products and processes) and (EP2) social pressure (e.g. stakeholders pay attention to companies' commitment on ethical issues, human rights respect, labour conditions) faced by the business unit.

We also control for 'internal pressure' (IP), i.e. the importance put at the business unit level on environmental and social issues. MNCs can introduce sustainability as a competitive weapon (Bansal & Roth, 2000; Klassen, 2001). This means that at the headquarter level sustainability is defined as a competitive priority and constitutes an internal pressure for subsidiaries to implement SM initiatives to a higher extent. This variable was calculated as the mean of three items based on a Likert scale ranging from 1 to 5, which measured the importance of environmental and social attributes of products and processes to win orders from major customers (see the Appendix for details). Summing these items is justifiable because the factors' Cronbach's alpha are greater than the threshold suggested by literature (0.7).

Finally, we control for network globalization and global sourcing. As pointed out in the literature (Gualandris et al., 2014), the impact of globalization on SM practices, is complex and not completely straightforward. On the one hand global networks and supply chains imply the difficult management of economic, financial, information and material flows across wider spatial horizons, the greater exposure to environmental factors and risks of all types and cultural and linguistic differences. From another perspective, however, global networks and supply chains can have a positive effect on MNCs' sustainable development. As a reaction to difficult communications and relationship management with remote partners that belong to different economic and socio-political contexts, companies can develop the extensive capabilities necessary to mitigate such issues. To avoid such confounding effects, we control for network globalization, which is captured by a dummy variable equal to one when plants of the same network are located in different continents, and for global sourcing, which is measured using the percentage of purchases made outside of the continent where the plant is based.

Factor Analysis

To understand whether the items discussed above load on separate constructs, we used exploratory factor analysis (EFA) (principal component with varimax rotation). Many criteria were considered to guarantee the reliability and validity of these measures. First, reliability was guaranteed by adequate Cronbach's Alpha scores (see Table 2). Then, the convergent validity of the constructs was assessed by the total variance explained and high factor loadings (higher than one). The separation of the construct into distinct factors with minimal cross loading provides support for discriminant validity. According to the literature (Nunnally *et al.*, 1967; Bagozzi *et al.*, 1991), the results show that all items consistently refer to their respective constructs. Table 2 shows the results of EFA.

Table 2 – Exploratory factor analysis with varimax rotation

items	Internal SM	External SM	Autonomy	Network integration	Supplier integration
SM1	.743				
SM2	.688				
SM3	.684				
SM4	.702				
SM5	.744				
SM6	.781				
SM7		.570			
SM8		.805			
SM9		.798			
A1			.874		
A2			.812		
NI1				.805	
NI2				.768	
NI3				.720	
NI4				.768	
NI5				.735	
SI1					.810
SI2					.786
SI3					.753
Cronbach's Alpha	.886	.852	.709	.867	.842

Results

In order to verify our research hypotheses we performed several multivariate regression models (Table 3). All the models include the control variables.

As regards to control variables, in line with the literature (Pagell, Yang, Krumwiede, & Sheu, 2004), company size is related to a higher adoption of SM, i.e. large companies adopt SM to a larger extent. The location of the plant is instead negatively related to SM initiatives, i.e. developing countries have a more significant adoption of SM than developed ones. This finding is quite counterintuitive and will require a future country-by-country analysis. The results show also that internal and external pressures are positively related to the adoption of SM. Network globalization positively and significantly impact the effort spent in implementing internal SM initiatives, while global sourcing do not exert direct effects on SM initiatives.

As regards to Autonomy, the coefficient is not significantly meaning that its effect is encompassed by other variables in the model, thus rejecting HP1. This result contradicts the literature (e.g., Golini et al., 2013) and more accurate analyses are needed to understand this finding. Next, we found that network integration is positively associated to internal SM while supplier integration is positively associated to external SM, confirming HP2 and HP3.

Table 3 - Regression analysis (Internal SM as a dependent variable)

	Model		
	1	2	3
SizeLn	.198	.197	.171
p-value	*.000*	*.000*	*.000*
IntPressure	.291	.289	.230
p-value	*.000*	*.000*	*.000*
ExtPressure	.105	.105	.090
p-value	*.021*	*.020*	*.031*
GlobalNetwork	.102	.101	.067
p-value	*.024*	*.027*	*.114*
Developed	-.182	-.181	-.175
p-value	*.000*	*.000*	*.000*
Autonomy	-	-.016	.048
p-value	-	*.702*	*.210*
Internal Integration	-	-	.354
p-value	-	-	*.000*
R-square	.494	.494	.598

Table 4 – Regression analysis (External SM as a dependent variable)

	Model		
	1	2	3
SizeLn	.127	.125	.083
p-value	*.004*	*.004*	*.032*
IntPressure	.341	.336	.266
p-value	*.000*	*.000*	*.000*
ExtPressure	.090	.091	.053
p-value	*.066*	*.062*	*.219*
Global Sourcing	-.010	-.010	-.006
p-value	*.820*	*.812*	*.875*
Developed	-.195	-.191	-.181
p-value	*.000*	*.000*	*.000*
Autonomy		-.036	-.040
p-value		*.408*	*.299*
External Integration			.426
p-value			*.000*

R-square	.259	.261	.430

Conclusion

Compared to the extant literature, this paper provides important insights about how sustainable management initiatives are triggered by factors related to the manufacturing networks. First, we show that autonomy seems not to be related to SM initiatives, both internal and external. This can be due to a counter-balancing effect. When autonomy is higher, the plant can arrange its own SM initiatives, when it is lower it can benefit from a higher internal integration.

Next we show that internal integration helps the development of SM initiatives at the plant level. As a consequence, multinational companies willing to develop SM within their networks should seek for higher integration in terms of information and resource sharing, ICT, performance measurement. However, this strategy can be particularly complex to develop when the networks are "footloose", i.e. the multinational company continuously changes production locations seeking for short-term advantages. Finally, we show how external integration helps the development of SM initiatives in collaboration with suppliers.

In conclusion, taking a global value chain perspective, in this paper we show how subsidiaries belonging to a MNC can contribute to sustainability of their internal and external networks. In particular, the global or geographical dimension seem to be secondary, compared to the positive effect that a higher level of integration (or tight forms of governance) can play.

This work is not free from limitations. Mainly, our data is limited to the practices of single subsidiaries. Thus, an interesting expansion of the analysis would be related to adopting the entire multinational network as the unit of analysis.

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Appendix

Table A.1 – Variables and measures

Measurements for dependent variables	
Sustainable Management	SM1. Environmental certifications (e.g. EMAS or ISO 14001)
	SM2. Social certifications (e.g. SA8000 or OHSAS 18000)
	SM3 Formal sustainability oriented communication, training programs and involvement
	SM4. Energy and water consumption reduction programs
	SM5. Pollution emission reduction and waste recycling programs
	SM6. Work/life balance policies
	SM7. Suppliers' sustainability performance assessment through formal evaluation, monitoring and auditing using established guidelines and procedures
	SM8. Training/education in sustainability issues for suppliers' personnel
	SM9. Joint efforts with suppliers to improve their sustainability performance
Measurements for independent variables	
Autonomy	1: You can make your own strategic decisions – 5: The strategy is set by another plant in the network or an international division
	1: This plant is autonomous in defining the production Plan – 5: Production plans are coordinated by another plant or an international division
Network Integration	NI1. Improve information sharing for the coordination of the flow of goods between your plant and other plants of the network (e.g. through exchange information on inventories, deliveries, production plants, etc.)
	NI2. Improve joint decision making to define production plans and allocate production in collaboration with other plants in the network (e.g. through shared procedures, shared forecasts)
	NI3. Improve innovation sharing / joint innovation with other plants (through knowledge dissemination and exchange of employees inside the network)
	NI4. Improve the use of technology to support communication with other plants of the network (e.g. ERP integration, shared databases, social networks)
	NI5. Developing a comprehensive network performance management system (e.g. based on cost, quality, speed, flexibility, innovation, service level)
Supplier integration	SI1. Sharing information with key suppliers (about sales forecast, production plans, order tracking and tracing, delivery status, stock level)
	SI2. Developing collaborative approaches with key suppliers (e.g. supplier development, risk/revenue sharing, long-term agreements)
	SI3. Joint decision making with key suppliers (about product design/modifications, process design/modifications, quality improvement and cost control)
Measurements for controls	
External pressure	EP1. Environmental pressure (e.g. stakeholders call for environmentally friendly products and processes)
	EP2. Social pressure (e.g. stakeholders pay attention to companies' commitment on ethical issues, human rights respect, labour conditions)
Intern. pressure	IP1. More environmentally sound products and processes
	IP2. Higher contribution to the development and welfare of the society
	IP3. More safe and health respectful processes
Location of the plant	Dummy built on the Gross National Income per capita of the country where the plan is located (World Bank 2012 data, measured in American Dollars, Atlas method) – 1 if the plant is based in a developed country (GNI>28000 Euro per capita)
Network globalization	Dummy equal to 1 if the respondent has indicated that its plant is part of a global manufacturing network ("plants are located in different continents")
Global sourcing	Percentage of raw materials, parts/components, subassemblies/systems purchased outside the continent
Size	Number of employees of the plant

Nurturing business ecosystem to enable paradigm shift: case of emerging wireless telecommunications industry in China

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Abstract

This paper aims to unveil the paradigm shift of China's wireless telecommunications industry from industrial catching-up paradigm to beyond catching-up paradigm through the co-evolution of key elements within business ecosystem. By conducting in-depth case study and draw roadmap of China's indigenous 3G/4G standard, the authors identify the key elements in business ecosystem as technology, institution, ecosystem configuration and ecosystem capability. The co-evolution of these elements is comprehensively analyzed. Then this paper discusses the paradigm shift of China's wireless telecommunications industry from the perspectives of technology accumulation mode, domestic standard's evolution path and the way of involving in business ecosystem. Through analyzing the paradigm shift of China's wireless telecommunications industry, the authors hope to provide guidance to emerging countries' industrial development beyond catching-up.

Keywords: Business ecosystem, China, Paradigm shift, TD-SCDMA, TD-LTE,

1. Introduction

Traditionally, the Western dominant designs are considered to be equal to "international" dominant designs as most of them are enacted by Western MNCs and international agencies. In recent years, the global industrial landscape begins to change and some Asian countries like China have been able to develop their own standards. These emerging Asian countries seek to shift their development paradigm from being just a standard-adopter to a co-shaper, and in some areas a lead shaper of international standards (Ernst, 2011). Explorations made by these countries in their own technical trajectories could be seen as the efforts to transform from technology catching-up paradigm to beyond catching-up paradigm.

Owing to their specific institutional and market circumstances, the choice of development paradigm made by large emerging countries like China may be more complicated than that in other countries. One of the most representative cases that experience paradigm shift is China's wireless telecommunications industry. It has transformed from adopting international standards in 1G (first generation) and 2G (second generation) stages to establish indigenous 3G (third generation) and 4G (fourth generation) standards. In this process, the business ecosystem including different vendors specialized in chipsets, base stations, core networks or related software sectors, government and intermediate agencies need to be nurtured and work together. When emerging technologies like emerging telecommunications standard emerges emerging markets, the uncertainties inherent in the two collide and interact with each other, and more researches are needed to explore the possible consequence. We aim to answer the following research questions:

Q1: What are those paradigm shifts in China's wireless telecommunications industry?

Q2: How does the business eco-system evolution support the paradigm shift?

This paper concentrates on the business ecosystem at industrial level whose evolution involves the increasingly complex relationships among main industrial players. In addition to the central role of focal firm, government's intervention in macro level and Industry Association in meso-level play a critical role in coordinating the co-evolution of stakeholders. Based on the case of China's wireless telecommunications industry, we will explore China's paradigm of industrial development and then link the evolution of business ecosystem to the industrial paradigm shift.

The rest of the paper is structured as follows: a literature review is conducted on the business ecosystem theory and the path dependency/shift. The research gap will also be identified. Then the theoretical framework on the paradigm shift through business ecosystem's evolution in emerging countries was proposed. The methodology part will address the research strategy, and specify the data collection and data analysis methods. Thereafter we present the case studies on how China nurture business ecosystems to enable paradigm shift of wireless telecommunications industry. Based on the above, three transformations in China's wireless telecommunications industry are identified. Finally, the conclusions and future researches are discussed.

2. Literature review

2.1 Literatures on Business ecosystem

The concept of business ecosystem was firstly proposed by Moore in 1993, by expanding the previous network theories from supply chain towards other levels of organizations like universities, industry associations and other stakeholders. It addresses the co-evolution between industrial systems and their dynamic environment. The business competition has evolved from the firm vs firm, supply chain vs supply chain towards ecosystem vs ecosystem (Rong, Shi and Yu, 2013). The key idea of a business ecosystem is to embrace the contribution from all the relevant stakeholders (Rong et al., 2013). However, although the previous works have covered the scope of the business ecosystem around the emerging industry(Battistella et al, 2013), the interaction and co-evolution among the key elements of business ecosystem are still unclear. Regarding to China's wireless telecommunications industry, it is necessary to study the paradigm shift through exploring the co-evolution of business ecosystem.

2.2 Path dependency and shift

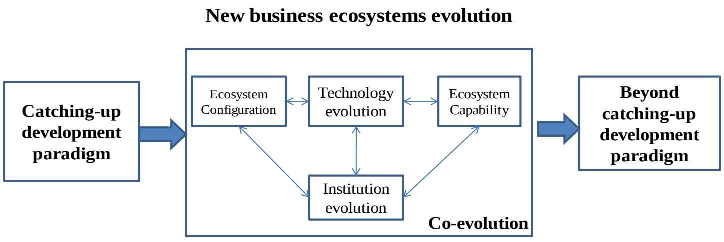
In the literature of technology trajectories and innovation strategy, the concept of path dependency was first developed by David (1985) and Arthur (1989) in order to explain why certain technologies are used widely and even predominantly despite the fact that they would seem suboptimal in terms of technological and/or economic efficiency. Actually, path dependence may be attributed to organizational forms, institutions, regions, fields and practices (Krugman, 1990) and, like organizational routines (Nelson and Winter, 1982) and institutional contexts (North, 1990), these are also highly relevant to the constitution of technological path dependency in the form of 'technological paradigms' (Dosi, 1982) and 'dominant designs' (Anderson and Tushman 1990). Furthermore, there exists the possibility that strategic action of the actors within the trajectory can actually cause a break away from the previous path. Considering the 'soft' elements of a complex technology, which are needed to make the technology work (Fleck and Howells 2001), the path shifting attempts will be extremely challenging under developing contexts (Lee and Lim 2001).

Traditional catching-up theory analyzed developing countries' development dynamics, mechanisms and trajectories. For example, Lee and Lim（2001）proposed the “path following”,” path skipping” and “path creating” catching-up paradigms of developing countries. However, these researches do not consider the paradigm shift in technology accumulation, institutional intervention and capability establishment. This study seek to explore the paradim shift of developing country from catching-up paradigm to beyond catching-up paradigm to explore the new mode and mechnism of trigering industrial reorganization.

2.3. Research framework

In this research, we seek to build the theoretical framework to explore the mechanism of paradigm shift base on business ecosystem's evolution as presented in figure 1. In the process of transforming from catching-up paradigm to beyond catching-up paradigm, substantial amount of effort need be devoted to promote the nurturing and interaction of key elements in business ecosystem.

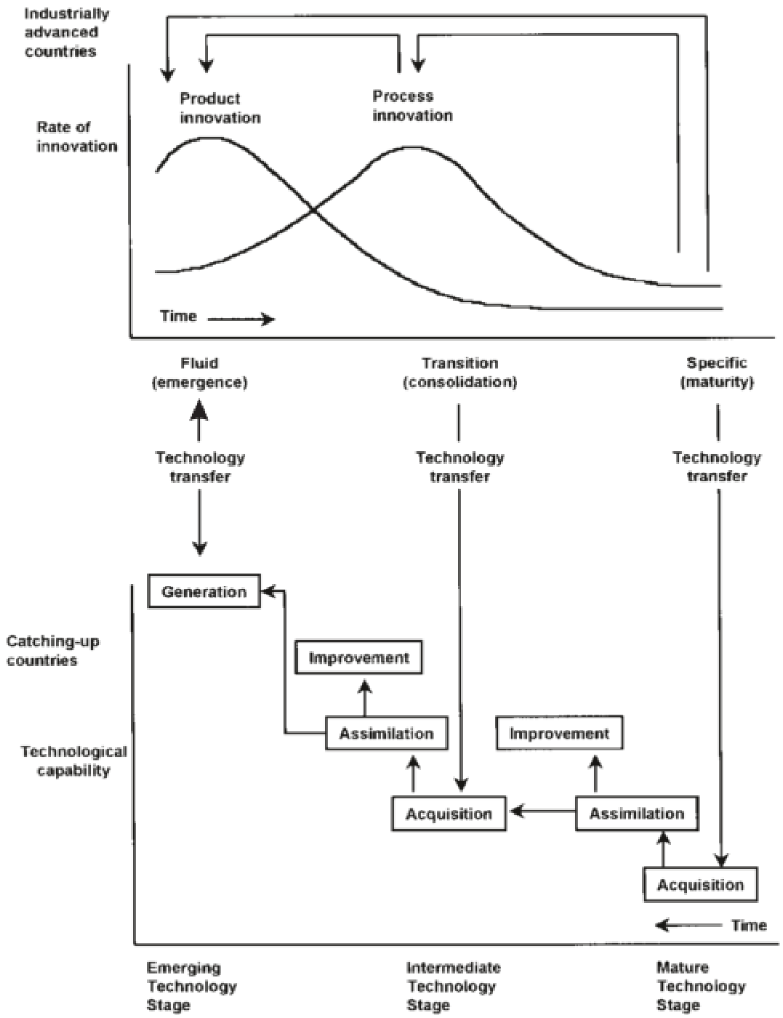
Figure 1: Research framework



On the basis of researches in the electronics industry in Korea, Kim (1980) developed a three-phase model-acquisition, assimilation and improvement-to extend Utterback's model. In this model, the developing countries rely on foreign technologies in technology learning. The companies in these countries always establish production capability by acquiring the total solutions including the process knowledge in assembly, the tacit knowledge in production and among others from foreign companies. After these assimilating processes were accomplished in one company, the related technologies are much easier to diffuse to other companies through the mobility of talents. Then the entrances of large amount of domestic players intensify the competition and enable the production of differentiated and localized products base on internal R&D.

Lee et al.(1988) postulate that the three-stage technology trajectory in developing countries takes place not only in mature technologies in the specific stage but also in growing technologies in the transitional technology stage and emerging technology stage as shown in figure 1. As for developing countries, they reverse the direction of technology trajectory in advanced countries and evolve from the mature technology stage (for duplicative imitation), to the intermediate technology stage (for creative imitation), and to the emerging technology stage (for innovation) as shown in figure 2. As for emerging technology, developing countries have the opportunities to conduct key patents layout, explore technology trajectory or establish standard concurrently with developed countries. It involves both technology transfer and learning through substantial investment in R&D activities.

Figure 2 Technological trajectories



数据来源：Kim, L. (1999).

Following the analysis above, catching-up and beyond catching-up paradigms are emerged as the development paradigms of developing countries. In catching-up paradigm, developing countries follow the trajectory from imitation to innovation based on accumulating progressively higher capabilities from production adaptation to duplicative imitation up to R&D-based innovation (Kim, 1997). The firms in these countries always engage in the mature technologies developed by foreign companies, and thereby reap the benefits of "second mover" advantages (Kim, 2012). While in beyond catching-up paradigm, developing countries draw on the resources to change or create technologies and components of production systems beyond achieving a technological catch-up (Figueiredo, 2014). The firms in developing countries seek to change to the positions of scientific and technological leadership and become first-movers and standards-setters by nurturing business ecosystem for emerging technologies concurrently with developed countries (Suttmeier & Yao, 2011). In the effort to nurture emerging industry, the develop paradigms of developing countries need to be shifted through the interaction and co-evolution of key elements within business ecosystem. The key elements identified in business ecosystem are as follows.

The evolution of emerging technology

The evolution of emerging technology is identified as the development, inheritance and change of technology activities, technology theme which include the emerging of new technologies and the substitution of existing technologies. Emerging technology system include large amount of subsystem. The evolutions of different technology systems determine the industrial innovation mode and frequency（Lee and Lim ,2001）.

The evolution of business ecosystem capability

Business ecosystem capability could be described as the ability that a firm organize the intra-firm and inter-firm resources and create value (Arbuthnott, 2010). The capabilities were formed in the process of ecosystem emerging and growth to promote the evolution of ecosystem's configuration. Base on Park's research in 2012, three major capabilities are identified corresponding to their specific characteristics as shown in Table 1. These capabilities include the dimensions of networking among actors, acquiring knowledge and skills, and leveraging policy and institutions.

Table 1 Distinctive characteristics of information system and the three major required capabilities

Distinctive characteristics	Required capabilities of each characteristic	Major required capabilities
Project-based multi-firm alliances.	Ability to integrate the capabilities of many firms harmoniously.	Networking their capabilities among various actors.
High degree of buyer involvement in innovation.	Ability of suppliers to collaborate closely with buyers.	
Various actors: government agencies, regulators, and small- and medium-sized enterprises, as well as large suppliers and buyers.	Ability of various actors to collaborate closely and integrate their capacities harmoniously.	
High complexity: many components and design routes, high customization, and various materials and inputs.	Broad and deep knowledge and skills for understanding the many diverse elements	Broad, deep, and integrated knowledge and skills.
Emergent and unpredictable properties: a small change in one part can lead to a large change in another part.	Integrated knowledge and skills for understanding the interaction among the elements	
Market is institutionalized or politicized, and heavily regulated or controlled.	Leverage the capability of institutions and policies to allocate the benefits to the actors	Leveraging institutions and policies.

Sources：Park, T. Y. (2012)

The evolution of ecosystem configuration

The configuration study is very popular to comprehensively understand a system as a whole in organization level (Walsh et al., 2005), manufacturing network (Kenney and Pon, 2011), global engineering network (Phaal and Muller, 2009) and supply chain network (Lee and Park, 2005). Jacobides et al. (2006) consider industry configuration is the common framework determines the nested structures of industry organization. It could be depicted through the methods of structural matrix design, hierarchical table network figures（Baldwin and Clark, 2000）. In the concept of business ecosystem, its configuration highlight the co-evolution of mutual dependence community which means the relationship among actors are not merely based on value chain but the community that share the same responsibility and evolution direction. The ecosystem capability accumulated in the former paradigm is possible to inherit in the later paradigm, while the ecosystem configuration tends to be reorganized.

The evolution of institution

Scott (2001) identify three institutional pillars-regulative, cultural-cognitive, and normative as an analytic tool of institution. Based on the classification of Scott (2001), Kshetri, Palvia & Dai (2011)use the government supports and rules, perception of national security and economic threat, and strength of nationalism to measure regulative institutions, cognitive institutions and normative institutions respectively. The institutional elements entail internal complexity. Even the different sub-industries of the same industrial system have distinctive demands to institutional environment in emerging context. As for developing countries, the feasibility of both mission-orientated policy paradigm that emphasize state promoted technology breakthrough and diffusion-orientated policy paradigm that address the widely application of innovation were also further analyzed in the following Sections (Ergas, 1987).

3. Methodology

This paper adopts the in-depth case study methodology to examine the paradigm shift through business ecosystems' evolution. The case of China's wireless 3G and 4G standard were selected due to their potential of the generalization of the proposed theoretical concepts and framework (Yin, 1994). To map the evolution of business ecosystem, technology roadmap method is adopted. Technology roadmap is a flexible technique to provide a structured means to demonstrate the relationship between evolving and developing markets, products and technologies over time (Phaal et al., 2004). As it is a flexible approach, in terms of China's indigenous 3G and 4G standard, four dimensions have been selected over time in order to structure the roadmap picture: resources, collaborations/networks, components/products and system. The relationships among different dimensions are also identified in the roadmap. As a result, the technology roadmap is a synthesis method to explore the co-evolution of different elements within business ecosystem.

The data sources are include annual reports of relevant firms, specialized telecommunications journals, official industry reports and professional magazines. We read, sorted, and abstracted related information from these collected documents. Another method for data collection is the semi-structured interviews. To enhance our understanding about the development paradigm of China's wireless telecommunications standardization, we conduct interviews with 10 senior executives from firms, officials from government agencies like Ministry of Industry and Information Technology (MIIT) and Ministry of Science and Technology (MOST). After the face-to-face interviews, the opinions of these informants were further investigated by email and telephone contacts to validate the collected data. Considering the complexity of this study, the data collected by these different means were triangulated and cross validated before use (Strauss & Corbin, 1998). Appendix presents the interview arrangements for the research.

4. Case study and analysis: The paradigm shift through business ecosystem evolution

4.1 Background

4.1.1 The diffusion of 1G and 2G standard in China

China initially started its 1G mobile service in 1987 based on the advanced mobile phone system (AMPS) analog system. 2G digital services such as the global system for mobile communication (GSM) were provided in 1995. Since the late 1980s, China's 1G mobile systems have relied on direct import from two foreign vendors, Motorola from the USA and Ericsson from Sweden. When foreign equipment companies entered China's market at the beginning of the 1990s, the market was totally dominated by foreign firms. From 2001 to 2002, China invested USD31.7 billion in the 2G mobile telecommunication network infrastructure and the market was still dominated by four major foreign vendors – Motorola, Ericsson, Nokia and Siemens – which controlled more than 90% of the GSM system market (CCID (China Center for Information Industry Development), 2003). At the end of 2002, the number of mobile subscribers in China had reached 334.8 million, which meant China owned the largest number of mobile users in the world.

4.1.2 The nurturing of China's indigenous 3G/4G standard

Stage 1: TD-SCDMA (Time Division-Synchronous Code Division Multiple Access) standard development (before 2001)

In May 2000, TD-SCDMA developed by China was accepted by ITU (International Telecommunications Union) as one of the three 3G standards. This maybe the first time a China-sponsored platform standard became an international standard. TD-SCDMA development was overseen by MII (Ministry of Information Industry), which was replaced by MIIT (Ministry of Industry and Information Technology) due to the restructure of China's government system in 2008 (MIIT, 2008). Datang as a state-controlled firm was responsible for the commercialization of TD-SCDMA system (Yan, 2007). At this stage, the Chinese government never made it clear that TD-SCDMA standard will be definitely deployed in China (Li, 2010; Yang and Lu, 2010). Due to the high institutional and technology risks, only a few MNCs like Siemens proactively supported TD-SCDMA before 2001.

4.2 Stage 2: TD-SCDMA standard commercialization and value chain building (from 2001 to 2009)

In this stage, TD-SCDMA standard contained high risks in further commercialization and adoption. For example, the very weak TD-SCDMA value chain set many difficulties to future commercialization. To overcome these difficulties, China's government took three kinds of measures to support the commercialization of TD-SCDMA. First, MII allocated 155MHz frequency band to TD-SCDMA in 2002 which showed the government's resolution in supporting the home-grown standard considering the scarcity of radio spectrum. Second, China's government began to adjust the policy of "exchange market for technology" from the late 1990s, and finally set the indigenous innovation as a national strategy in 2006 (Chen and Liu, 2008). Third, in April 2008, China Mobile was arranged to offer TD-SCDMA services with the trial networks in Beijing and other seven cities during the Beijing Olympic Games (Gao, 2009).

4.3 Stage 3: Standard's commercial deployment and evolution towards 4G (After 2009)

In January 2009, China Mobile got the TD-SCDMA license and started to provide large scale TD-SCDMA services in 10 large cities. The TD Industry Alliance which was established in October 2002 grew rapidly from 8 domestic companies in 2002 to 53 companies including 30 foreign firms by the end of 2010 (Gao & Liu, 2012). In this stage, China actively conducted the R&D of TD-LTE (Time Division Long Term Evolution) standard. In January 2012, TD-LTE was approved by ITU as one of the two global 4G standards (TD Forum, 2010). Different from TD-SCDMA, TD-LTE is a more internationalized standard involving broad ranges of foreign operators and equipment vendors. China Mobile actively dedicated to the standardization and commercialization of TD-LTE by investing 6.7 billion USD to roll out TD-LTE networks in 2012 (China Telecommunications Net, 2010). To study the evolution of China's indigenous wireless standard, the roadmap of China's TD-SCDMA and TD-LTE standard were drawn in figure3, figure4, figure5 and figure6.

Figure3: Road map of TD-SCDMA from 1997 to 2002

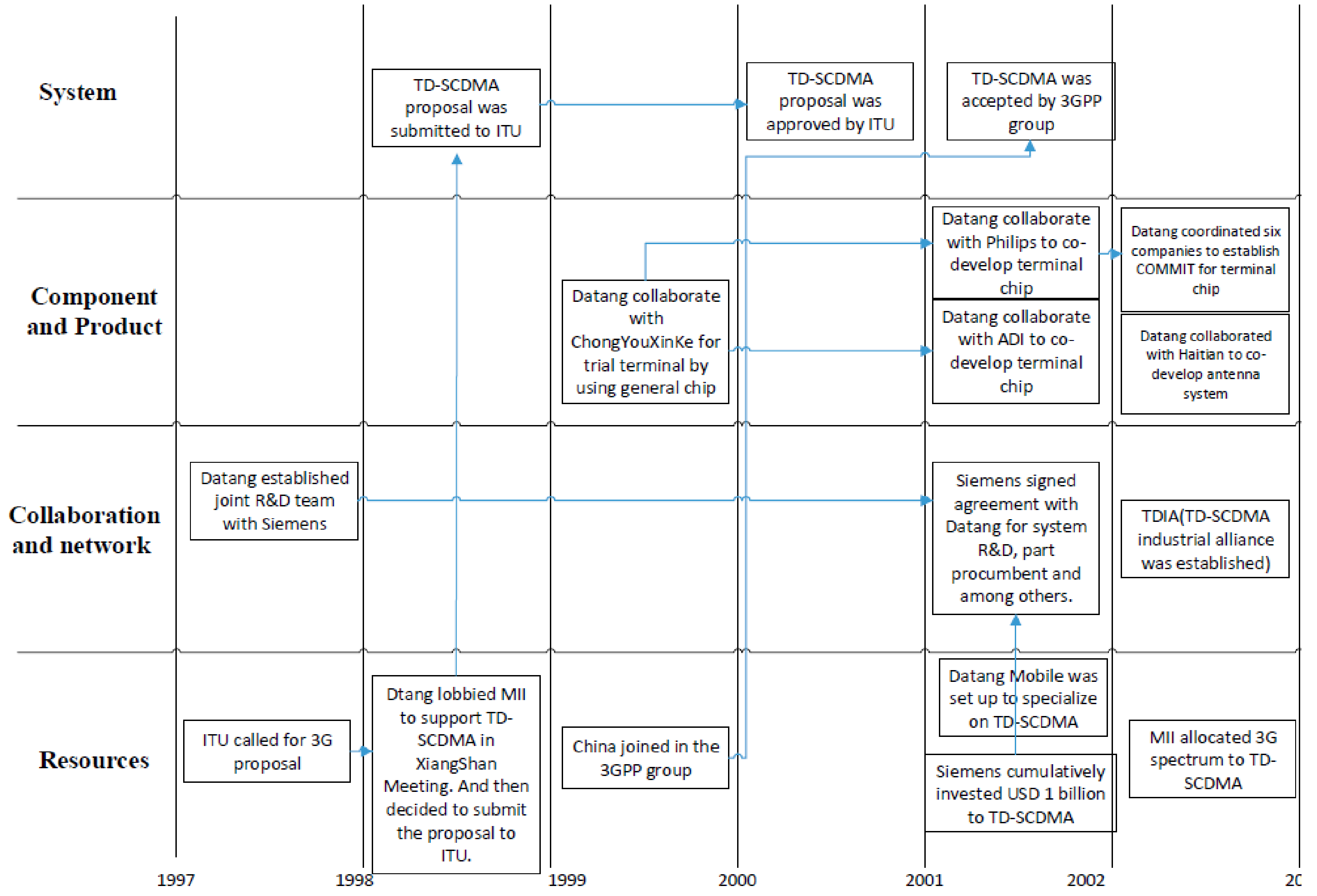


Figure4: Road map of TD-SCDMA from 2003 to 2009

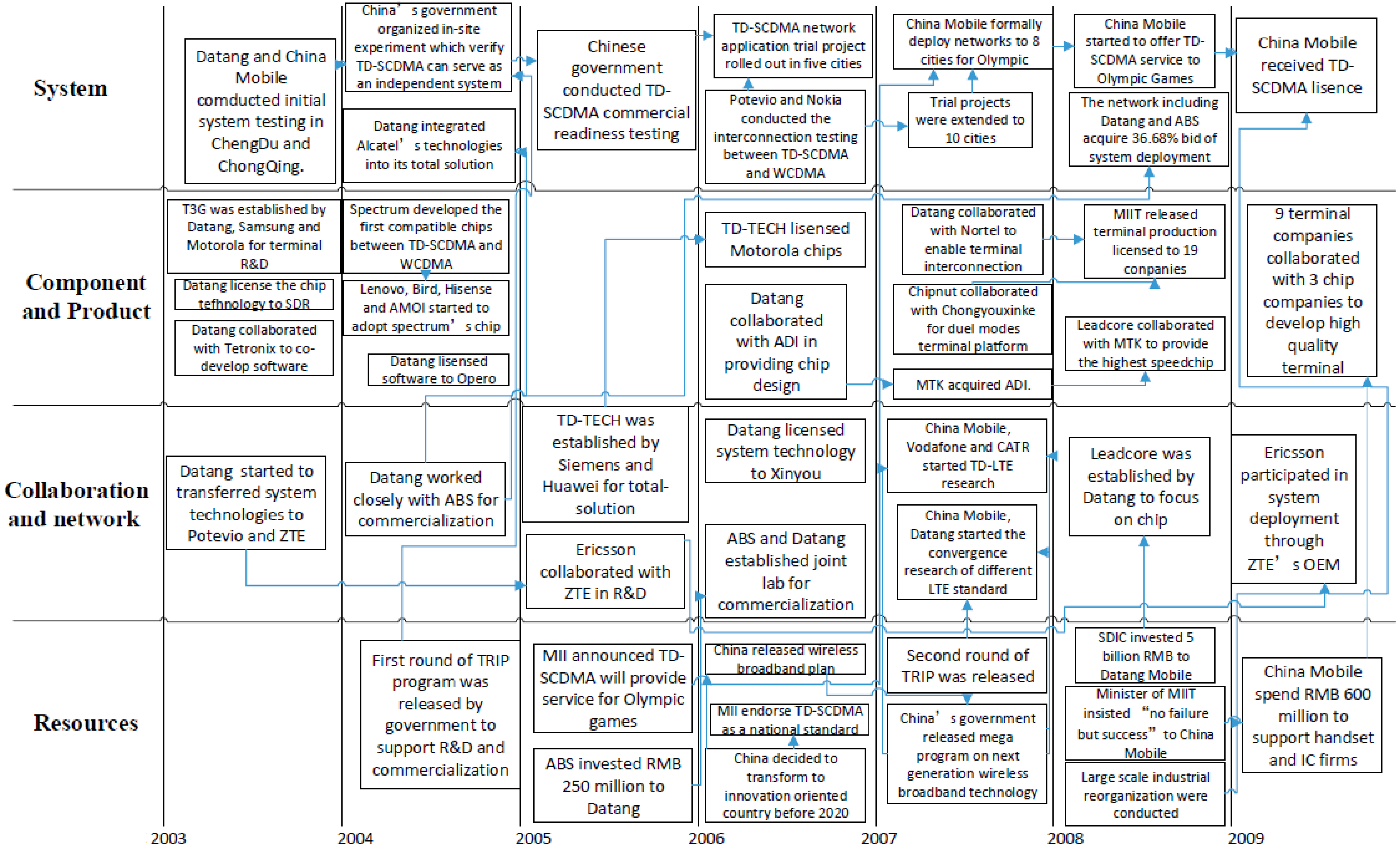


Figure5: Road map of TD-LTE from 2004 to 2008

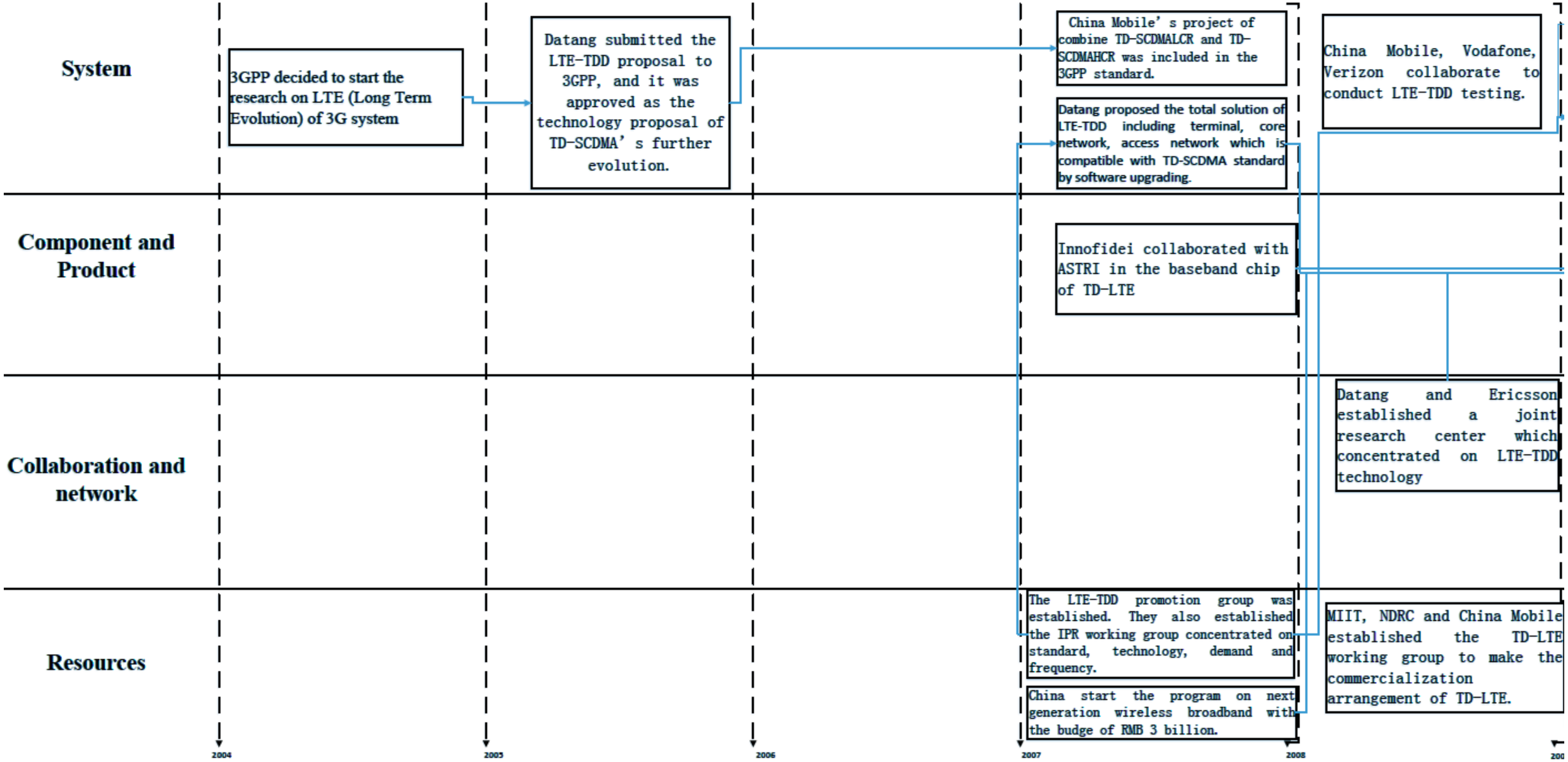
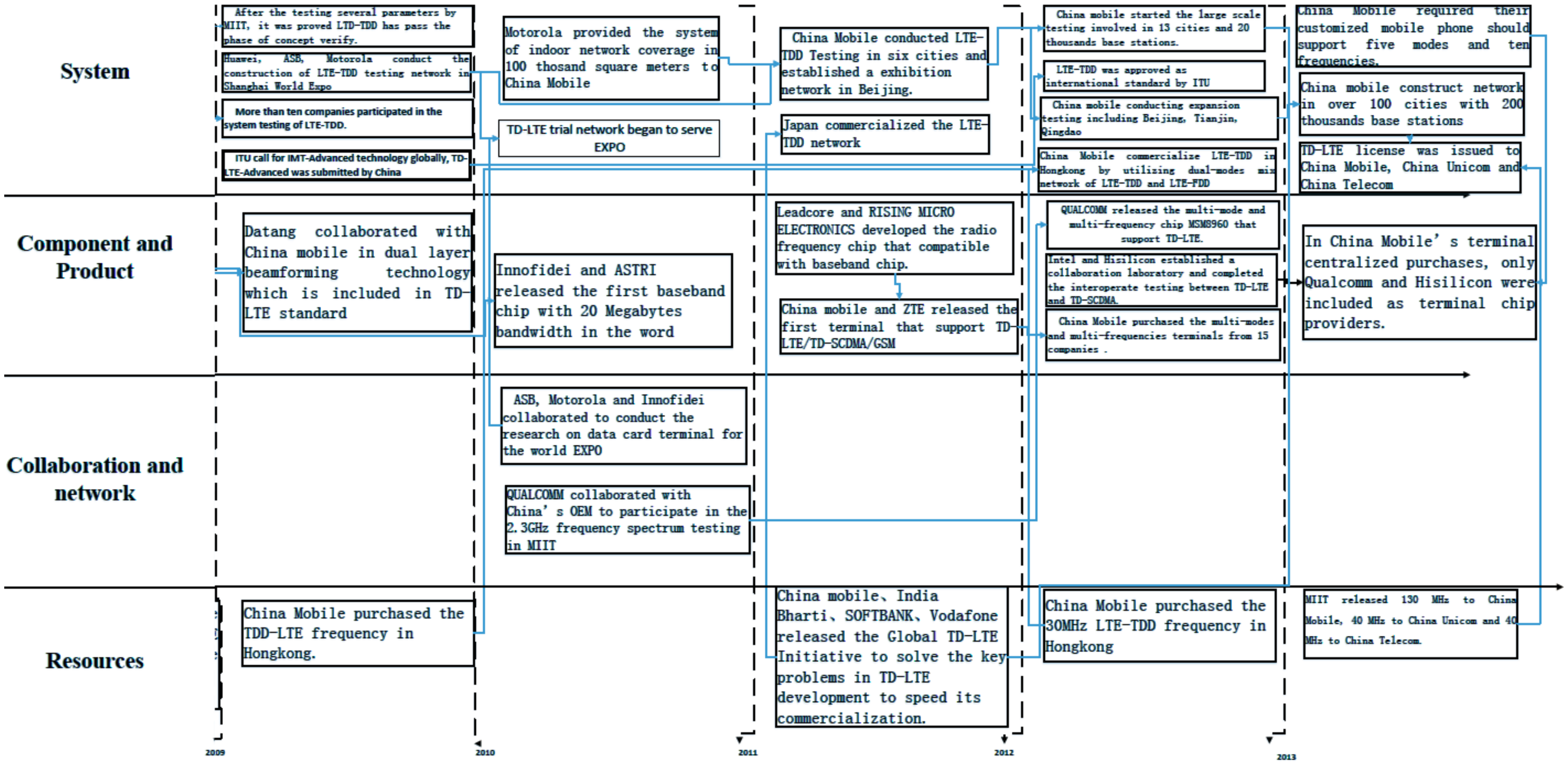


Figure6: Road map of TD-LTE from 2009 to 2013



4.2 The process of paradigm shift from business ecosystem evolution perspective

4.2.1 The evolution of emerging technology

Wireless telecommunications standards adoptions in China have evolved from 1G to 4G through different trajectories. In 1G and 2G stage, China adopted Western standards. From the 3G stage, China decided to establish indigenous standard after missing the opportunities of establishing standard and relying on foreign companies in 1G and 2G standard[1]. Then China devoted large amount of efforts to commercialize the indigenous 3G standard. After verifying the feasibility of TD-SCDMA standard in technology and commercialization, MIIT approved TD-SCDMA as China's first 3G standard in January 2006. Then China mobile started to establish TD-SCDMA trial networks in eight cities in March 2007.

China awarded operation licenses to both Western WCDMA (Wideband Code Division Multiple Access) and CDMA2000 (Code Division Multiple Access 2000) standards and home-grown TD-SCDMA standards in January 2009. Therefore, Western standards WCDMA, CDMA2000 competed with Chinese TD-SCDMA in China's market. In 4G stage, WCDMA and CDMA2000 evolved to FDD-LTE (Frequency Division Long Term Evolution), while TD-SCDMA evolved to TDD-LTE (Time Division Long Term Evolution). And the standards in 4G stage were increasingly convergence considering the similarity between FDD-LTE and TDD-LTE. After the accumulation in TD-SCDMA stage, TD-LTE, an upgraded version of TD-SCDMA, was also adopted as one of the two 4G mobile communication standards by ITU in early 2012 (Kwak et. al., 2012). Then MIIT granted TD-LTE licenses to all of China's operators include China Mobile, China Unicom and China Telecom in December 2013.

4.2.2 The evolution of emerging institution

In the large emerging countries like China, institutional elements play a critical role in wireless telecommunications development. Policy-makers need to leverage mission and diffusion policy paradigms to balance the national and business interests which are usually intertwined. The comparison of different policy paradigm is presented in Table 2. Moreover, given the high uncertainties and risks of the emerging wireless telecommunications standard, fostering technology leadership and developing services capabilities are two strategic dynamics that are important but also sometimes difficult to balance for the policy-makers. In 1G and 2G stage, China tended to adopt diffusion oriented policy paradigm by establishing service capability through using western standard. And largest market share was acquired by western companies before 2000. In 3G and 4G stage, China started to adopt mission oriented

[1] For a TD-SCDMA timeline from the Siemens Perspective, see http://www.TD-SCDMA-tech.de/pr-art.htm (accessed 11 September 2008).

policy paradigm through large amount of government's investment in R&D and network deployment. China also formulated a set of technology policies which can help its domestic IT industries to build technology leadership and finally change the situation of low-level imitation of foreign technologies. For example, in January 2006, China's government initiated a 15-year plan for science and technology development, which was aimed to transform China into an innovation-orientation society by 2020. Particularly, the government has actively supported domestic firms to compete with international giants in core technologies of wireless telecommunications.

Table2 the comparison of different policy paradigms

	Mission-orientation policy	**Diffusion-orientation policy**
Strategic dynamics	Technology leadership	Services capability
Technology change properties	Disruptive	Incremental
Pursuing interests	National interest	Business interest

In 2006, China announced the Next Generation Wireless Broadband Program, a Mega Program under the national 10th Five-Year Plan which aimed to support the R&D of some strategic products and technologies (MOST, 2006). In December 2007, the Mega Wireless Program was launched by the State Council with a budget of 3 billion USD by 2012 (Ming & Ouyang, 2008). In this program, the government designated the prioritize R&D targets and the different development projects for each key technological fields as shown in Table 3. In 2008, the National Wireless Mega-program was launched, which include 4G technology as a focus of national support. A senior official of MIIT in charge of China's Wireless Mega-program we interviewed commented:

"China hopes to establish strong technology capability in the next generation wireless telecommunications. Our future technology researches will base on large and comprehensive networks with multiple systems. We will pay enough attention to develop TD-LTE standard, as 4G cellular system will be the backbone of China's wireless telecommunications industry.

Table 3 Contents of China's Mega Wireless Program

Development fields in China's Mega Wireless Program	Number of special development projects launched			
	2008	2009	2010	2011
R&D&C of TD-SCDMA enhanced version	10	4	0	0
R&D&C of LTE	14	11	6	10
R&D&C of IMT-Advanced mobile phone and Internet access services	11	4	3	0
Mobile network, application and terminal	7	3	4	4
R&D&C of broadband wireless access	3	2	2	0
R&D&C of short-range wireless interconnection system and sensor network	10	7	2	0
Broadband and short-range wireless access	0	0	2	3
Generic wireless technology	4	3	0	0
Post wireless technology	0	0	0	4
Internet of Things	0	0	3	5

Source: The data was collected form MOST (2011) http://www.nmp.gov.cn/, and then compiled by the author.

4.2.3 The evolution of ecosystem configuration

Wireless telecommunications is a dynamic industry that experience quickly evolution. Attracted by domestic large market, large amount of telecommunications equipments and terminal companies entered China through collaborating with China' companies in 2G stage. In this stage, the configuration of business ecosystem is characterized by domestic service providers serve as the focal firm, foreign equipments, chips, terminal companies serve as the main supplier while domestic supplier serve as supplements. In the effort to transform from this catching-up paradigm to beyond catching-up paradigm, China need to reorganize the business ecosystem's configuration, nurture the indigenous business ecosystem and promote the co-evolution of configuration with other elements within the business ecosystem.

China transformed to beyond catching-up paradigm through establishing indigenous standard and cultivating competitive industrial players along the value chain. In the early development stage of TD-SCDMA standard, large amount of key technologies and components were at the preliminary stage of R&D, especially for the related chipsets. In October 2012, Datang, Soutec, Holley, Huawei, Lenovo, ZTE, CEC and Potevio founded the TDIA (TD-SCDMA Industry Alliance) with the support of the Chinese government to promote the R&D and commercialization of standard[2].

[2] Website of TD Alliance, http://www.tdscdma-alliance.org/

Before the commercialization of TD-SCDMA standard in 2009, Datang served as the focal player to attract industrial player, diffuse related technologies and nurture the business ecosystem. The configuration of business ecosystem is presented in figure 7. After the commercialization of TD-SCDMA, China mobile as the operator take the responsibility of focal firm to promote the growth of business ecosystem through coordinating wide industrial players. As the largest single operator with more than 400 million subscribers in 2006, China Mobile was in a powerful position to influence the evolution direction of the mobile telecommunications standard. The fixing of China Mobile as the TD-SCDMA operator by the central government clearly demonstrated the latter's commitment to develop indigenous standard. In March 2009, China mobile coordinated the industrial terminal and chip companies through investing 90.9 million USD to develop TD-SCDMA handsets. Nine terminal companies and three chipset companies engaged in this project (China Mobile, 2009). The configuration of TD-SCDMA business ecosystem after commercialization is presented in figure 8.

Figure 7: business ecosystem of China's TD-SCDMA standard before commercialization

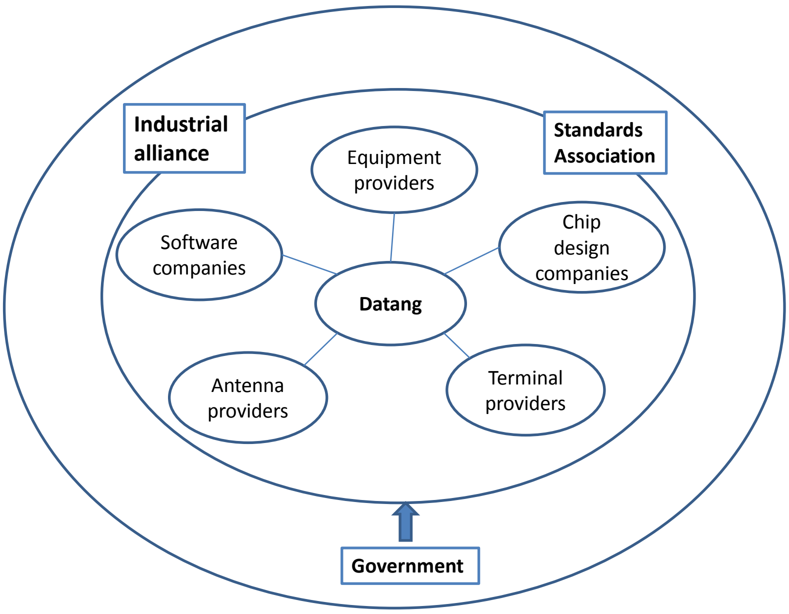
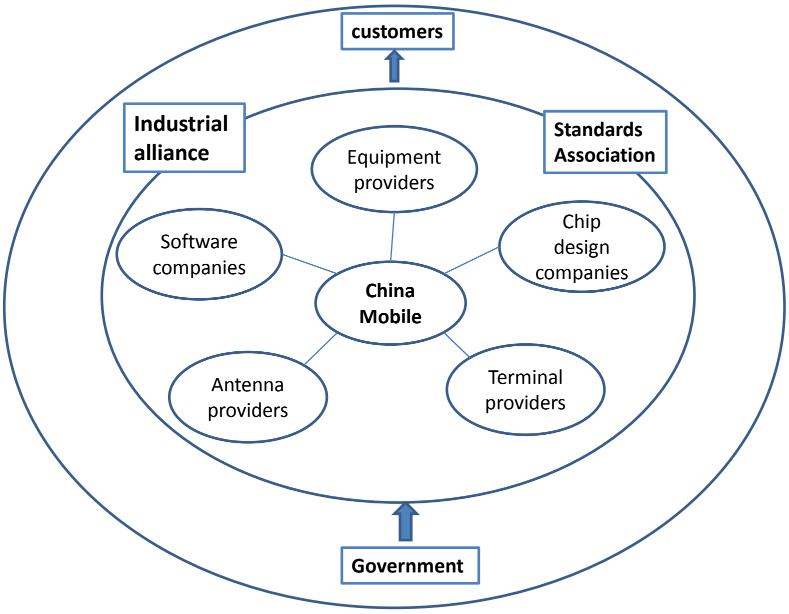


Figure8: business ecosystem of China's TD-SCDMA standard after commercialization



The further evolution of TD-SCDMA seems to be more open and internationalized. China Mobile actively works with Vodafone and Verizon Wireless to explore the TD-LTE together with FDD LTE as a high-performance and low-cost evolution option leading to the 4G standard platform. NGMN (Next Generation Mobile Networks China) was established by the main global service providers include China Mobile, Vodafone, Orange, NTTDoCoMo, T-Mobile, KPN and Sprint in March 2006 to focus on the R&D of TD-LTE standard. By the end of 2013, there were 23 TD-LTE commercial networks in 18 countries with more than five million subscribers (MIIT, 2013). An interviewee, a senior manager in China Mobile who was in charge of TD-SCDMA network deployment comments:

> *Now China Mobile will make full efforts to supply TD-SCDMA services to the market. As the TD-SCDMA network still needs more commercial tests and fine adjustments, we really hope that more vendors will join the industrial chain to build the TD-SCDMA industry together. At the same time, we are collaborating with global mobile operators and vendors to explore the LTE version of TD-SCDMA leading to 4G.*

4.2.4 The evolution of ecosystem capability

Based on the characteristics of China's wireless telecommunications industry, the required capabilities are condensed to three elements as networking various actors, broad, deep, and integrated knowledge, and leveraging institutions and policies. As for the capability of networking their capabilities among various actors, the power to influence and coordinate other industrial players are critical to technology assimilation and accumulation. The focal firm Datang collaborated with foreign firms like Siemens, Philips and ADI for technology accumulation. Then Datang transferred these technologies to other industrial players. For example, Datang shared chipset technologies with Chongqing Chongyou information technology group. Through coordinating and organizing the network of industrial players and promoting technology diffusion, the business ecosystem include system equipment, chipset, terminal, testing and antenna were gradually nurtured.

In the capability of broad, deep, and integrated knowledge, technology capabilities were gradually accumulated along the value chain. In November 2004, MII established the “TD-SCDMA R&D and commercialization” program to conduct the indoor and outdoor experiments with four system companies, four chipset companies and twelve terminal companies. After the systematic technology research, simulation study and verify testing, it is proved that TD-SCDMA was capable of large scale system deployment. Based on the accumulation in TD-SCDMA stage, China’s companies quickly made breakthrough in the R&D of TD-LTE. In June 2005, Datang submitted the LTE-TDD proposal to 3GPP, and it was approved as the technology proposal of TD-SCDMA’s further evolution. Then in September 2007, China mobile’s project that combined TD-SCDMALCR and TD-SCDMAHCR was included in the 3GPP standard.

The capability of leveraging institutions and policies by focal players are essential in promoting the growth of TD-SCDMA’s business ecosystem. Datang which was state own company administrated by SASAC (State-owned Assets Supervision and Administration Commission) was established by restructuring China Academy of Telecommunications Technology. This background advantage enabled Datang to promote TD-SCDMA’s development through leveraging institutions and policies factors. For example, in Xiangshan meeting held in 1998, most people opposed proposing TD-SCDMA standard to ITU. After Datang lobbied MII to support the standard, the decision was made to submit TD-SCDMA standard proposal to ITU. In the commercialization stage of TD-SCDMA, China mobile conducted TD-CDMA trial network testing and was designated as the service provider of TD-SCDMA in the early 2000s. After realizing China mobile was not actively devoted to the domestic standard, Datang reported the difficulty of TD-SCDMA’s commercialization to MII. In 2008, the minister of MIIT met the experts of China mobile and addressed that “as a national standard, TD-SCDMA could not be failed”. This effectively promoted the devotion in network deployment and value chain nurturing by China Mobile.

4.3 Case analysis: the co-evolution of business ecosystem's key elements

4.4.1 The co-evolution of emerging technology and business ecosystem's configuration

In 2G stage, the key technology of China's wireless telecommunications industry was controlled by foreign companies. Foreign equipment, terminal, and chipset companies played an important role in China's business ecosystem and acquired larger amount of market share than domestic companies in 1990s. In 3G stage, China started to nurture the domestic players within the business ecosystem in the process of establishing indigenous standard. In TD-SCDMA's case, the evolution of business ecosystem's configuration supported the development of emerging technology. Through nurturing industrial players and enabling their collaboration, the technologies on TD-SCDMA standard were rapidly developed. The business ecosystem established in TD-SCDMA stage further supported the technology R&D and commercialization of TD-LTE standard considering the latter was the further evolution of the former as ITU identified. In 4G stage, driven by the similarity between TD-LTE and FDD-LTE standards and the international adoption of TD-LTE standard by global operators, more MNCs participated in the development of TD-LTE standard.

4.4.2 The co-evolution of emerging technology and business ecosystem's capability

Along with the evolution of emerging technology, the capability of leveraging institutions and policies, networking various actors, and broad, deep and integrated knowledge were consistently improved. In 1G and 2G stage, government promulgated relative open policies towards MNCs and provided limited protection to the domestic equipment companies. In 3G and 4G stages, enabled by national cognitive institution of accumulating industrial nurture experience and the normative institution of developing indigenous standard, the business ecosystem of China's indigenous standard gradually acquired the capability to leverage institutions and policies. In the business ecosystem, the focal firm like Datang and then China Mobile could coordinate the R&D and commercialization of different participants and promote the diffusion of relative technologies. In 4G stage, the dynamic of industry development was transferred from government's support to broad, deep, and integrated knowledge. The technology capabilities and new products developing experience accumulated in TD-SCDMA standard provided a basis for the releasing of domestic TD-LTE chipsets, terminals and system equipments. In China mobile's network deployments in 13 cities, China's companies totally acquired 60 percent orders on equipments procurement and construction whereby Huawei occupied 25 percent, ZTE had 23 percent and Datang acquired 13 percent[3]。

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[3]Website of China mobile procurement and bidding.
http://b2b.10086.cn/cmeppew/article/article.do?method=viewIndexData&i18n=zh_CN

4.4.3 The co-evolution of institution and business ecosystem's configuration

Institutional elements play an important role in restructuring business ecosystem's configuration and promoting paradigm shift in wireless telecommunications industry. In 1G and 2G stage, China's companies were locked in the existing western standards and architectures. China's government adopted diffusion policy strategies in establishing service capabilities, and it was quite open towards the competition between domestic and foreign firms. In 3G stage, after realizing there were only a few companies like Datang and Siemens participating in TD-SCDMA standard, MOST and MII organized six companies to establish TD-SCDMA industrial alliance to promote the growth of business ecosystem in October 2002. Then in May 2005, the minister of MOST proposed that they will consistently supported TD-SCDMA standard and encouraged more domestic and foreign firms involved in the standard to enlarge the business ecosystem. As the technology evolved to TD-LTE standard, MIIT established "the LTE-TDD promotion group" which included all service providers in China, China Academy of Telecom Research, Huawei, ZTE, Shanghai Bell and among others to concentrate on standard related technology, demand and frequency related issues.

4.4.4 The co-evolution of institution and business ecosystem's capability

The institutional factors in China's wireless telecommunications industry highly influenced the capabilities' evolution. First, government's intervention strongly promoted the establishment of industrial alliance and collaboration of industrial players. TD-SCDMA industrial alliance and large amount of formal collaborations were directly guided or supported by the government. Second, large amount of supports from government were given to chipset and terminal companies through national R&D programs to support the weak parts of business ecosystem. For example, two rounds of "TD-SCDMA R&D and commercialization program" and "wireless mega program" were established by the government to promote researches on the key technologies. Third, government's policy orientation shifted to support indigenous innovation from 2006, this enabled business ecosystem's capability of nurturing indigenous standard through leveraging institution and policy.

5. Discussions: The paradigm shift of China's wireless telecommunications industry

5.1 Transform from new entrants to incubators of business ecosystem

In 1G and 2G stage, domestic companies entered in the business ecosystem of wireless telecommunications industry through providing low cost and localized products to compete with foreign companies in domestic market. China opened the domestic equipment and terminal market to foreign companies from the early development stage of telecommunications industry in the late 1980s. At that time, the major domestic companies like Huawei and ZTE were just established. China's equipment and terminal market were controlled by foreign companies due to the weak competitiveness of domestic companies. For example, the foreign companies like Motorola, Nokia, Ericsson, Siemens, Lucent and Nortel monopolized China's 2G market before 2000. Until 1999, the domestic companies acquired marginal market share of 4 percent and 2 percent in switches and base stations respectively.

However, in 3G stage the competition mode was increasingly transformed from company level to business ecosystem level. China started to nurture the TD-SCDMA business ecosystem which involved in equipment vendors, chipset, terminal, software providers and among others. Supported and coordinated by the government, the chipset, terminal and system equipment providers gradually established the technology and product development capabilities. Its business ecosystems were also quickly growing through these nurturing efforts. China's equipment companies started to dominate domestic TD-SCDMA and TD-LTE equipment market in network deployment.

5.2 Transform from technology absorption to indigenous or collaboration R&D

In 2G stage, external technology imitation and reverse engineering were the main source for China's companies to catch up with foreign companies. By following foreign technology trajectory, China's companies minimized the initial investment and risk of R&D and then localized the products through incremental innovation. In 3G and 4G stage, China seeks to establish indigenous wireless telecommunications standard. As the existing technology learning mode was not feasible, China devoted into the R&D of TD-SCDMA standard through indigenous or collaboration R&D. For example, Datang established the research team of TD-SCDMA through collaborating with Siemens. China's government offered financial supports through public funding programs like TRIP and national mega wireless telecommunications programs.

5.3 Transform from the follower to the leader of standard evolution

Compare with fixed telecommunications system, the architecture and system of TACS standard in 1G stage and the GSM standard in 2G stage were relative closed where the key technologies were strictly protected by patents. Until November 1997, Huawei made breakthrough in GSM equipment. And then ZTE and Datang released their GSM system equipments. However, foreign companies like Ericsson and Nokia provided GSM systems to China's operators from 1995 when China started to adopt GSM standard. Considering GSM system's continuity, integrity and reliability, domestic operators would not take the risks to change to domestic system equipments. In this regard, domestic operators were locked in the standard system dominated by foreign companies.

China started to conduct the research of indigenous TD-SCDMA standard from the late 1990s. After more than ten years efforts, TD-SCDMA standard commercialized concurrently with other international 3G standards in China's market. In the 4G stage, TD-LTE standard was considered as the further evolution standard of TD-SCDMA by ITU and was approved as one of the two international 4G standard. China leaded the standard's evolution by proposing 4G standard almost concurrently with western countries and influenced the standards' evolution direction in 4G and beyond.

6. Conclusion

This paper explored how did China's wireless telecommunications industry transformed from industrial catching-up paradigm to beyond catching-up paradigm. Different elements like institution, technology, configuration and capability were identified within the business ecosystem to engage in and commit to the paradigm shift of domestic industry. We also explored the co-evolution mechanisms among different elements. Three kinds of paradigm shifts were proposed as technology accumulation mode, domestic standard's evolution path and the way of involving in business ecosystem in Table 4.

Table 4: Paradigm shift in China's wireless telecommunications industry

	Catching-up paradigm	**Beyond catching-up paradigm**
The mode of technology accumulation	Absorbing key technologies from foreign companies	Developing or co-developing indigenous technologies
The evolution path of domestic standard	Following the evolution of western standard	Creating the evolution path of indigenous standard and then seek to lead the evolution direction of global standard
The way of involving in business ecosystem	Participating in global business ecosystem	Nurturing indigenous business ecosystem

Since in current literature, systemic and fundamental studies are scarce on the developing countries' development paradigm beyond catching-up, this paper contributes to the existing catching-up theories by firstly studying the paradigm shift of wireless telecommunications industry in developing country through the co-evolution of key elements in business ecosystem.

Our study also suffers some limitations. This paper only conducts the case study of China's wireless telecommunications industry. It would also be better to expand the case scope to other emerging industries like high performance computing, semiconductor and among others to further explore and verify the business ecosystem theories, and to provide guidance to emerging countries' industrial development.

Appendix:

The interview arrangements

	Time	Interviewees	Organizations
1	Dec. 2010	Senior Manager	Strategy department of China mobile
2	Dec. 2010	Senior Manager	Market department of China Unicom
3	Dec. 2010	vice president	Huawei wireless group
4	Dec. 2010	Officials	Ministry of Science and Technology, Department of Policies and Laws
5	Dec.2010	Officials	National Development and Reform Commission, high tech department
6	May 2011	Officials	Ministry of Industry and Information Technology, national mega program
7	Jun. 2011	department manager	China national standardization management committee
8	July. 2011	Senior Manager	Research Institute of China Mobile
9	July. 2011	Senior Manager	Network department of China Unicom
10	Sept.2013	Senior Manager	Research Institute of China Mobile

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Synergistic Innovation Modes and Innovation Performance

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Abstract
In the context of open innovation, synergistic innovation has been the indispensable choice for small and medium enterprise. Based on a survey to 427 Chinese manufacturing SMEs from Yangtze River Delta, this paper empirically explores the relationships between different synergistic innovation modes and innovation performance of SME using the technique of structural equation modeling (SEM), and the mechanism how synergistic innovation modes influence the innovation performance is explored. The study finds that there are significant positive relationships between synergistic innovation modes(Strategic alliances mode, Patent collaboration mode, R&D outsourcing mode and Factors exchange mode) and innovation performance of SMEs, of which synergistic effect mediator the relationship between synergistic innovation modes and innovation performance.

Keyword: synergistic innovation mode, synergistic effect, innovation performance

1. Introduction

As economic development relies on the innovation of the firm, firms are required to conduct technology and institution innovation (Grossman, 1993). The manufacturing industry perform the main driving force of economic growth and social development, and small and medium-sized enterprise (SME) play a key role in the transition of a developing country. In other words, it is essential for SME to innovate in long-term growth and survival (Terziovski, 2010). However, it is difficult for SME to innovate by itself, because the resource shortage deriving from its feature of scale hinders the progress of innovation. Therefore, SME tend to undertake synergistic innovation to adjust the new complex and changeable environment (Lee et al., 2010).

While there are studies on SMEs' synergistic innovation behaviors and performance, few studies have explored the issue of organizational innovation mode from the perspective of synergy. Since the implementation of innovation-oriented national construction, many great efforts have been made by Chinese government to encourage SMEs to innovate synergistically. So many modes of synergistic innovation have emerged that SMEs have many choices to cooperate with other innovative actors. Our central question is: how do different modes of synergistic innovation influence the synergistic effect and innovation performance of manufacturing SMEs? What is the mechanism?

Synergistic effect is a dynamic result that the total benefits producing by the cooperators who pursue the same goal overweighs the added sum, and it emphasizes not the single one or part but the whole should be concerned simultaneously. Simply, it is an output of increasing-returns when two or more synergistic organizations cooperate with others, and the output is usually formulized as “1+1>2” and “2+2>5”.

It is a general problem for SMEs that how to undertake innovation when they have to face the fact of resource shortage. It is obvious that the synergistic effect plays a significant role in the development of emerging economics. However, can differences of innovation performance of enterprises be explained by the modes of synergistic innovation? Therefore, this paper investigates the role played by synergistic effect in the relationships between synergistic modes and innovation performance.

This paper was designed to examine the direct and mediating effects of synergistic effect on the relationship between synergistic modes and innovation performance in China. The paper contributes to the understanding of innovation performance in several specific ways, enhancing our theoretical understanding of synergistic modes, synergistic effect on the innovation performance of firms in emerging and transition economies. This study considering synergistic effect as a mediating variable between synergistic modes and innovation performance contributes to the literature by providing theoretical discussion and empirical validation on the relationship between synergistic modes and firms’ innovation performance. Next, despite researchers’ increasing recognition of the importance of synergistic modes (Das and Teng, 2000), there has been only limited investigation of the effects of different synergistic modes on synergistic effect and innovation performance, and this is especially true of synergistic modes domains in emerging economies.

This study contributes to the understanding of the mediating effect of synergistic effect on relationships between synergistic modes and innovation performance of firms in emerging and transition economies, and gives some new findings. Then, data from small and medium-sized manufacturing enterprises in the Yangtze River Delta are examined here. Overall, this approach contributes to a broader understanding of innovation modes in emerging economies and developing countries.

2. Theoretical development and hypotheses

Literatures on innovation show that during the last few decades, a systematic and fundamental change has been seen in the way firms conduct their innovative activities. In particular, the significance of synergistic innovation of SMEs has boosted interest in identifying its main mechanism from the perspective of synergy theory, a concept introduced by Ansoff for the first time in 1965. Compared with large-scale enterprises, SMEs domain fewer resources and less R&D funds, so SMEs have to face more instability, uncertainties and barriers to innovation. Moreover, firms increasingly rely on external sources of innovation by emphasizing the ideas, resource and individuals flowing among organizations, searching for and using a wider range of external resources and information (Zeng, Et al., 2010; Chesbrough, 2003). It is essential for SMEs to obtain innovative resources and market legitimacy for the creation of successful innovations for SMEs.

The notion of synergistic innovation is reflected in many modern theories that explain the collaboration of SMEs using concepts such as innovation network, total innovation management, and trade cost theory. Some scholars focusing on innovation network in external environment deem that relationship between synergistic innovation of SMEs and the innovation performance and the influence of patterns of synergistic innovation on firm performance (Zeng, Et al., 2010; Persaud, 2005; Lei et al., 201). They emphasize the relationships among the different innovation actors, Such as the relationship between firms and other firms, universities, government, research organizations, and intermediary institutions. As the development of synergistic innovation, a lot of collaborations of SMEs are emerging in innovation networks (Amara, 2005). In China, many SMEs are allied in Science Parks and industries clusters which can provide them an interactive network. Strategic alliances, which facilitates the accelerated flows of resources, information and trust necessary to secure and diffuse innovation among organizations, has emerged as an important mode of synergistic innovation (Eisenhardt and Schoonhoven, 1996). Some studies point that the alliances among the firms and universities, intermediated institutions, suppliers, and other SMEs have a positive influence on innovation performance. According to Pekkarinen and Harmaakorpi (2006) and Zeng (2010), SMEs could access the external resources and capabilities through external innovation alliance with other innovation actors. However, the competency might be reinforced during the process of alliance which would reduce the innovation performance (Das and Teng, 2006). According to the previous literature, the innovation mode of strategic alliance has a positive influence on innovation performance.

Some studies focusing on the knowledge management in the process of innovation for SMEs that emphasizes the knowledge-flow among the innovation organizations promotes innovation. The number of technology patent is an essential index to estimate the innovation performance and innovation capabilities. Many researches find that there exists a positive relationship between the number of patents and innovation performance (Chang et al., 2012; Guan and Gao, 2012; Hagedoorn and Cloodt, 2003). In recent years, globalized patent collaboration has been an emerging method for firms. Not only the inside resource accumulation should be continued, but also the firms should make full use the external resource and talents (Ma and Lee, 2008; Huang et al., 2012). Patent collaboration provides an important approach facilitating the knowledge spillover among the innovation actors which contributes to the innovation performance (Fritsch and Franke, 2004). In general, the innovation mode of patents collaboration has a positive influence on innovation performance.

Some studies focusing on the trade cost of innovation management for SMEs point that compared with major enterprises, it is necessary for SMEs to undertake R&D outsourcing to reduce cost of production and management (Freytag et al., 2012). There has been an important change in the form of organization structure the firms choose, from vertical integration organization to horizontal organization. More and more SEMs outsource their non-core R&D business of the firms to reduce the cost and to enhance its core capabilities. However, some studies argue that R&D outsourcing may make SEMs have too much reliance on the external resource and impede the exploration of tacit knowledge which leads to the reduction of innovation performance. But when the experience and the knowledge base of the firm have been well accumulated, the negative influence on innovation performance will be weakened (Weigelt, 2009; Macher, 2006). In general, the synergistic innovation mode of R&D outsourcing is a cost-cutting and less time-consuming method to market the products. The innovation mode of R&D outsourcing has a positive influence on innovation performance.

With the systemization of innovation activities and continuous extension of management field, the coordinate of innovation factors is increasingly demanded in the process of innovation. According to Xu, innovation capability of firms can be leveraged via the all-element innovation, which is an important part of TIM (Total Innovation Management). The elements in TIM theory, including technology, capital, talents, knowledge and instruments, and knowledge, are combined coordinated and it emphasizes that all the factors (funds, talents, knowledge, etc.) should be involved and exchanged in the innovation system. Compared with the factors-flow inside the factor exchange, the exchange of factors outside the factor exchange can effectively supplement scarce resources of SMEs (Inkpen and Tsang, 2005).Florida(2006) points that the talents of firms are not the fixed capital inside the origination but a kind of element capital that can flow flexibly among the originations. In general, the innovation mode of factor exchange has a positive influence on innovation performance.

In general, synergistic innovation modes can promote innovation performance. Hence, we propose that:

H1. The synergistic innovation modes have a positive impact on the innovation performance of SMEs.

H1a.Strategic alliances mode has a positive impact on the innovation performance of SMEs.
H1b.Patent collaboration mode has a positive impact on the innovation performance of SMEs.
H1c.R&D outsourcing mode has a positive impact on the innovation performance of SMEs.
H1d.Factors exchange mode has a positive impact on the innovation performance of SMEs.

In the fast-developing and continuous-changing global market, synergistic innovation of SMEs exerts a significant influence on the national innovation system and economies (Persaud, 2005; Ar and Baki, 2011). The definition of synergy first given by Ansoff in 1965 is that two or more enterprises share resources to develop together. Synergistic innovation means a complementary response to insecurity and uncertainties of innovation arising from the context of rapid developing. The fundamental goal of synergy innovation is to creating more value. Synergistic effect output by the participants overweighs the added sum, and like an invisible hand, the synergistic effect promotes the innovation system. It can be formulated as“1+1>2” or “2+2>5”.From the perspective of trade cost theory, the synergistic effect can be realized by reducing the cost and enhance the innovation performance.

In general, the innovation mode of factor exchange has a positive influence on innovation performance. Hence, we propose that:

H2.The synergistic effect has a positive impact on the innovation performance of SMEs.

Synergistic effect is a dynamic result that the total benefits producing by the cooperators who pursue the same goal overweighs the added sum, and it emphasizes not the single one or part but the whole should be concerned simultaneously. Some literature on synergistic innovation has pointed that different modes of synergistic innovation should be taken according to the characteristic of the firms to promote the innovation process (Von Hippel, 1976). Hagedoorn and Cloodt (2003) argue that the number of patent and the R&D input have a significant impact on synergistic effect. Itami and Roehl(1991) points that synergistic innovation mode can improve the coordination between tangible resource of firms and the intangible resource, such as tacit knowledge. Some studies find that the mode of R&D outsourcing facilitates the absorption and transference of knowledge, and thereby realize the synergistic effect. Some scholars explore the relationships among innovation actors, such as firms, universities, government, research organizations, and intermediary institutions, argue that the alliance, the elements exchanging, the patent collaboration among the organizations all promote the synergistic effect(Fu and Qu,2009). In general, the innovation mode of factor exchange has a positive influence on innovation effect. Hence, we propose that:

H3.The synergistic innovation mode has a positive impact on the synergistic effect of SMEs.

H3a.Strategic alliances mode has a positive impact on the synergistic effect of SMEs.
H3b.Patent collaboration mode has a positive impact on the synergistic effect of SMEs.
H3c.R&D outsourcing mode has a positive impact on the synergistic effect of SMEs.
H3d.Factors exchange mode has a positive impact on the synergistic effect of SMEs.

On the basis of literature and hypothesis, the tentative model is represented in Fig. 1. The figure indicates the relationships between different synergistic innovation modes and innovation performance of SMEs. It supposes that there are positive relationships between synergistic innovation modes and innovation performance of SMEs.

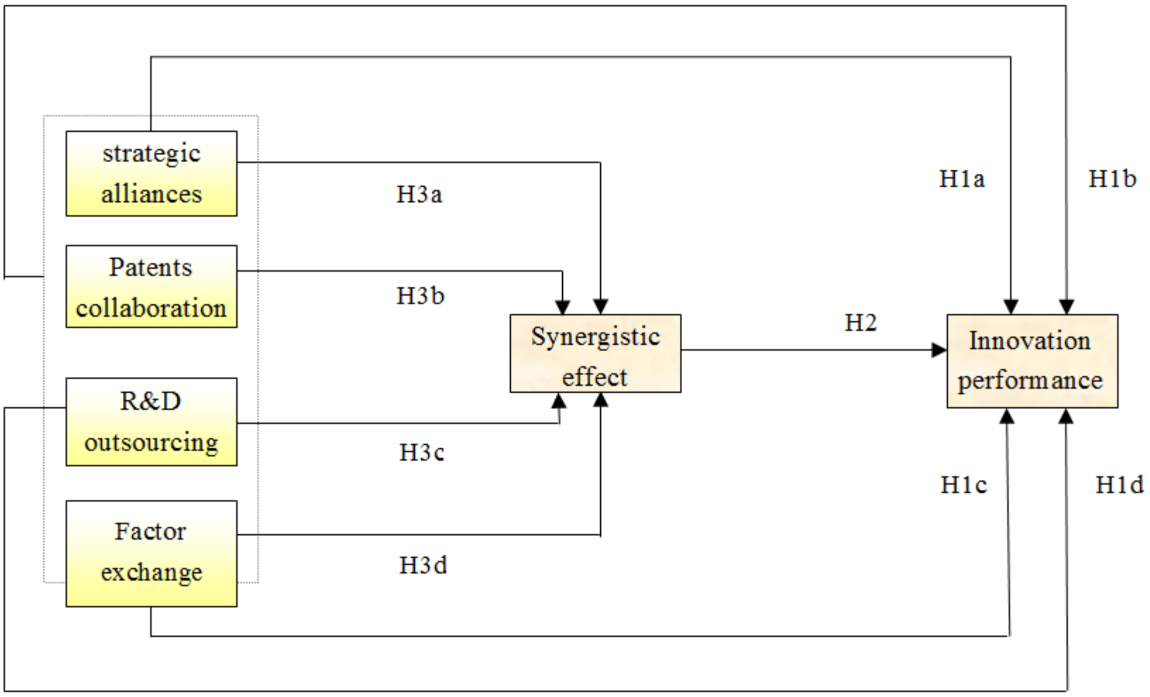

Fig.1. the hypothesis frame work

3. Research methodology

Background

China has undergone dramatic changes since the opening policy. Yangtze River Delta, as the important area of emerging economics, exerts a critical influence on innovation development. It generates a large number of SMEs surrounding this area and contributes a high level GDP. Therefore, this paper chose the data from 427 Chinese manufacturing SMEs from Yangtze River Delta as the sample.

Servey design and data source

Table1 presents the constructs and their measures in this study. The constructs in our study are based on the previous studies on Modes of synergistic innovation (e.g., Zeng et al., 2010; Mache, 2006; Chen & Xu, 2007), synergistic effect (e.g., Audretsch and Keilbach, 2011) and innovation performance (e.g., Romijn and Albaladejo, 2002). The measures are adjusted and applied to the specific context of Chinese SMEs. The items of constructs are assessed with a 5-point Likert scale, with "1" being "very low" and "5" being "very high". The questionnaire was pre-tested for validity to a panel of experts in the related field (including the executives of enterprises, consultants, scholars and government officers).

Table1. Constructs and measures

Constructs	Items	Authors
Strategic alliances	With other firms, with government agencies, with intermediary institutions, with research organizations, with universities, with financing institutions	Zeng et al., 2010 [68]; Chen.2004 [72]
Technical patent	Patent purchases, patent licenses, patent usage	Hagedoorn and Cloodt, 2003[37]
R&D outsourcing	program outsourcing, outsourcing expenditure, establish or merger a firm	Macher,2006
Factors exchange	Technology factors, knowledge factors, talents factors, funds factors	Xu, 2007
Synergistic effect	resource profile, knowledge creation, tacit knowledge ratio, Turnover and surplus, input-output ratio	Audretsch and Keilbach, 2011[60]
Innovation performance	Patent increase, radical innovation products, incremental innovation program, innovation Annual turnover of new products	Romijn and Albaladejo, 2002; Fischer et al., 2001

The data were collected via across-sectional survey approach by sending questionnaires to 605 manufacturing SMEs randomly, with 305 paper questionnaires and 300 electronic questionnaires from SMEs located in the region of Yangtze River Delta. There are two methods to send questionnaires that one is visiting a firm and another one is investigating the MBA students who take responding office. Eight weeks later, 517questionnaires were received, in which were 427 valid, with a response rate of 85.45 % and a valid response rate of 82.59.

Measurement

In this investigation, respondents were asked to indicate the extent of their firms in different modes of synergistic innovation (strategic alliances, technical patent, R&D outsourcing, Factors exchange),synergistic effect, and innovation performance. Moreover, the items of constructs are assessed with a Likert scale ranging from 1 to 5 with the following equivalences, ‘‘1: very low’’; ‘‘2: low’’; ‘‘3: neutral’’; ‘‘4: high’’; ‘‘5: very high’’.

The sample

Table 2 indicates that there are, in terms of regions, 40% come from Shanghai, 30%come from Zhejiang and 30% come from Suzhou. In terms of ownership, there are12% State-Owned Enterprises (SOEs), 34% Collectively Run Enterprises (CREs), 48% Private Enterprises (PEs) and 6% Foreign-Invested Enterprises (FIEs).59% of firms have employees ranging from 300 to 1000. 92% of firms have an annual turnover ranging from 20 to 40 million RMB Yuan.

Table 2. Characteristics of the sample

Characteristics	Number of enterprisers	Percentage (%)
Regions		
Shanghai	171	40
Zhejiang	128	30
Suzhou	128	30
Age(year)		
<3	8	2
3-5	48	12
6-10	132	31
11-15	107	25
>15	132	31
Ownership		
SOEs(State-owned Enterprises)	51	12
CREs(Collectively-Run Enterprises)	145	34
PEs (Private enterprise)	205	48
FIEs(Foreign-funded enterprises)	26	6
Number of employees		
<20	17	4
20-300	157	37
300-1000	253	59
Annual turnover (million RMB)		
0-3	8	2
3-20	26	6
20-40	393	92

4. Results and analysis

Analyzed using AMOS 17.0, the results of the study are presented in table 3 including statistics for the measurement scales and a measurement model. Constructs are all greater than 0.7. A Cronbach's α of 0.70 or greater means acceptable levels of reliability. The measurement model with all 25 items is analyzed as a confirmatory factor analysis. The result of measurement model is shown that the reliabilities of individual items are acceptable.

Table 3. Internal consistencies and liability of scale construct

Latent Variables	Observed Variables	Cronbach's α	TITC value
	With other firms		0.605**
	with government agencies		0.791**
Strategic alliances	with intermediary institutions	0.894	0.677**
	with research organizations		0.768**
	with universities		0.732**
	with financing institutions		0.748**
	Patent purchases	0.861	0.636**
Patent collaboration	Patent licenses		0.807**
	Patent usage		0.776**
	Program outsourcing	0.769	0.754**
R&D outsourcing	Outsourcing expenditure		0.728**
	Establish or merger a firm		0.711**
	Technology factors	0.890	0.758**
Factors exchange	Knowledge factors		0.807**
	Talents factors		0.742**
	Funds factors		0.729**
	Resource profile	0.773	0.533**
	Knowledge creation		0.592**
Synergistic effect	Tacit knowledge ratio		0.583**
	Turnover and surplus		0.485**
	Input-output ratio		0.541**
Innovation	Patent increase	0.847	0.632**
performance	Radical innovation products growth ratio		0.750**
	Incremental innovation products growth ratio		0.703**
	Innovation Annual turnover of new products		0.662**

Moreover, the measurement model shows acceptable fit values for RMSEA, CFI, GFI, and TLI in table 4, and it shows that the model performs well in explaining the relationships between latent variables and observed variables. Therefore, this model is the basis for designing the structural model. The basic causal model, incorporating the hypothesized relationships, is revealed in Fig. 2. That presents the hypothetical structural equation model by AMOS 17.0.

Table 4. Fit statistics for measurement model

Statistic		Value
χ2		837.553
DF		321
χ2/DF		2.609
RMSEA		0.075
Goodness-of-fit index	（GFI）	0.903
Tucker-Lewis Index	（TLI）	0.923
Comparative fit index	（CFI）	0.912

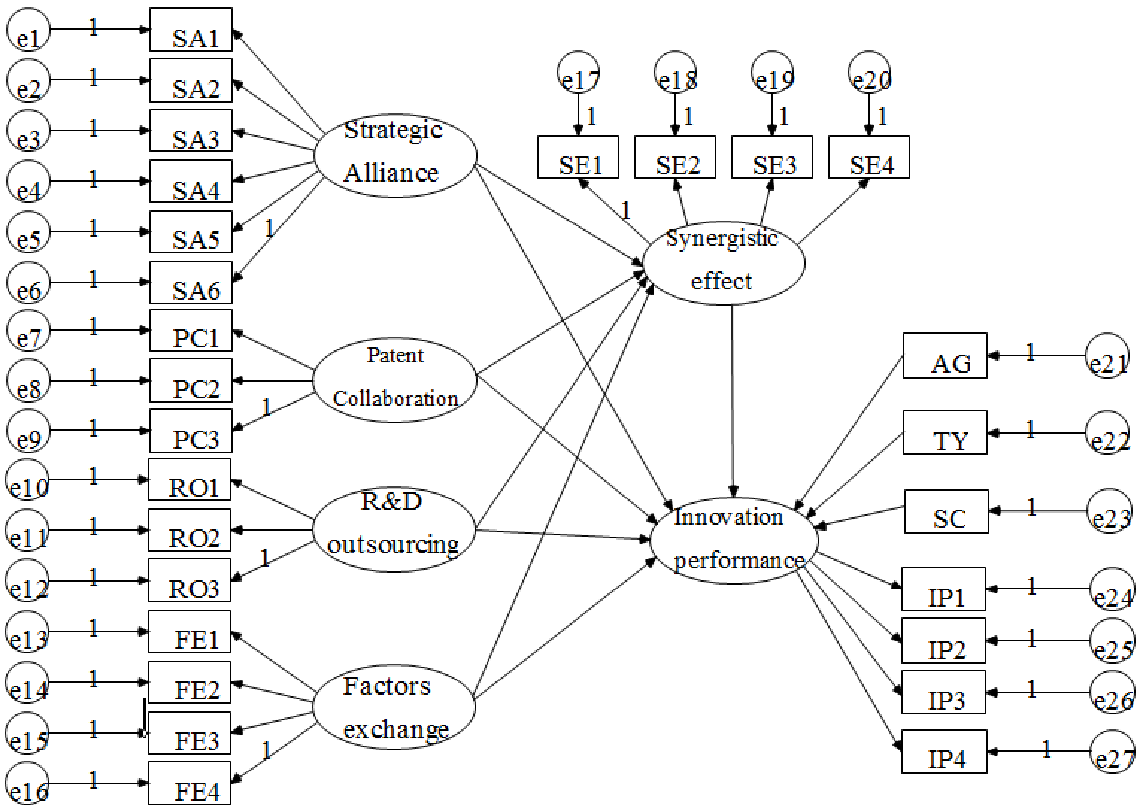

Fig. 2. Full structural equation model in AMOS

Causal model

The results of the AMOS analyses are summarized in Table 4. The coefficients and error terms of the causal model are shown in Table 5.Analyses of each hypothesis can be made with an examination of the structural coefficients with in the causal model. Table 5 provides the paths, the respective standardized parameter estimates and t-values. It shows that there are significant positive relationships between synergistic innovation modes (Strategic alliances mode, Patent collaboration mode, R&D outsourcing mode and Factors exchange mode) and innovation performance of SMEs. There are significant positive relationships between synergistic innovation modes (Strategic alliances mode, Patent collaboration mode, R&D outsourcing mode and Factors exchange mode) and synergistic effect. The synergistic effect exerts a positively influence on the innovation performance.

H1 predicts the paths from SA (Strategic alliances), PC (Patent collaboration), RO (R&D outsourcing) and FE (Factors exchange) to IP (Innovation Performance)(H1a, H1b, H1c and H1d, respectively). The path coefficients from SA, PC, RO and FE are positive (g11=0.635, g12=0.443, g13=0.703and g14=0.128) and significant. Therefore, H1a, H1b, H1c and H1d are supported. The results shows that all kinds of the synergistic innovation modes have significant positive influence on the innovation performance, and various modes have different impact on innovation performance of SMEs. An interesting finding is that the mode of R&D outsourcing has the most significant positive impact on innovation performance of SMEs, while the role of mode of factors exchange played in promoting the innovation performance of SMEs is relatively small. This new finding may be related to the efficiency of R&D of SMEs in China. And a possible explanation is that compared with other three modes, the mode of factor exchange exerts a low level synergy for SMEs, and in turn there is no time for SMEs to accumulate knowledge and resources from external environment which leads a low innovation performance.

H2 predicts the paths from SE (Synergistic Effect) to IP (Innovation Performance) (H2).The path coefficients from SE (Synergistic Effect) to IP (Innovation Performance) are positive and significant. Therefore, H3 is supported. This finding reveals that the “synergistic effect” positively promotes the innovation performance of SMEs.

H3 predicts the paths from SA (Strategic alliances), PC (Patent collaboration), RO (R&D outsourcing) and FE(Factors exchange) to SE(Synergistic Effect)(H3a, H3b, H3c and H3d, respectively). The path coefficients from SA, PC, RO and FE are positive (g11=0.797, g12=0.702, g13=0.936 and g14=0.343) and significant. Therefore, H3a, H3b, H3c and H3d are supported.

5. Conclusions

On the basis of a sample of 427 manufacturing SMEs, this paper has empirically explored the relationships between different synergistic innovation modes and innovation performance of SMEs in China. The findings indicate that there are significant positive relationships between synergistic innovation modes and innovation performance of SMEs, of which the mode of R&D outsourcing is the most significant. In addition, in line with the findings of Wagner (2002) and Lohrke (2006), the results reveal that there are significant differences in impact of different types of synergistic innovation modes on innovation of firms. These findings confirm that the mode of R&D outsourcing plays a more distinct role in synergistic innovation for SMEs than other modes.

Table 5. Path estimates and hypothesis confirmation.

Path			S.E.	C.R.	P	Standardized coefficient
Strategic alliances	→	Innovation performance	0.084	12.365	***	0.635
Patent collaboration	→	Innovation performance	0.072	8.327	***	0.443
R&D outsourcing	→	Innovation performance	0.106	7.446	***	0.703
Factors exchange	→	Innovation performance	0.031	4.273	***	0.128
Strategic alliances	→	Synergistic effect	0.047	18.488	***	0.797
Patent collaboration	→	Synergistic effect	0.036	8.317	0.011	0.702
R&D outsourcing	→	Synergistic effect	0.115	8.184	***	0.936
Factors exchange	→	Synergistic effect	0.039	5.440	***	0.343
Synergistic effect	→	Innovation performance	0.125	12.286	***	0.793
Age	→	Innovation performance	0.024	0.946	0.344	0.039
Type of industry	→	Innovation performance	0.050	2.698	***	0.102
Scale	→	Innovation performance	0.066	3.553	***	0.173

Based on the above analysis, policy recommendations and implications are given as follows:
It should be noted that not all synergistic innovation modes improve synergistic effect and innovation performance to the same extend. It follows that policy can be effective when they focus on the efficiency of the differences of synergistic innovation modes. Policy maker should place greater emphasis on effective synergistic innovation modes. Also, it should be noted that not all synergistic innovation modes improve innovation performance through the role of synergistic effect. Policy maker should place greater emphasis on the mode which promotes synergistic effect effectively. SMEs are required to seek synergistic mechanism and synergistic innovation modes which improve their synergistic effect.

However, several limitations of this study should be addressed. One of which is that the empirical results are investigated from a sample of Chinese SMEs and hence that findings might be country-specific. In the future studies samples of SMEs from other developing countries should be used to test and extend these findings. Next, the Likert scale used to assess the items of constructs in our study is indeed affected by flaws in measurement. So caution needs to be exercised in generalizing the findings of this exploratory study. In addition, some interesting issues such as the moderator effects, such as entrepreneurships, should be explored in future research.

Regardless of these limitations, our study has made several contributions to the study of SMEs and synergistic innovation literatures. Firstly, based on the previous theories, this study classified synergistic innovation of SMEs into four modes (Strategic alliances mode, Patent collaboration mode, R&D outsourcing mode and Factors exchange mode). Compared with some case studies in China on synergistic innovation, our study explored the mechanism how synergistic innovation promotes innovation performance. Second, our findings provide some important implications for managers and policy makers concerned with the management of synergistic innovation. From a manager viewpoint, it reflects that different synergistic innovation modes have different impact on synergistic effect and innovation performance, and valid modes should be used to source external knowledge and resources. From a viewpoint of policy, more polices in favor of the synergistic effect among the innovation actors for SMEs should be made.

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Logistics innovation solutions for re-distributed manufacturing

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Abstract
Increasingly, both academics and practitioners have been reporting on the drive towards what has been termed *"re-distributed manufacturing"*, a move away from centralized to distributed production and from global (offshored) to more local (near-shored) manufacturing.. This is associated with various changes in transport and labour costs, availability of materials and energy, the need for sustainability, increasing demand for customised products and services, the availability and cost of small-scale equipment, easier access to information and ever shorter product life cycles. These changes are, in turn, leading to the development of new business models and supply chains (SCs). The purpose of our paper is to explore why and how global logistics companies are developing innovative business models that allow them to better support their customers in their journey of re-distributing their manufacturing around the world. An in-depth longitudinal case study is presented. The case company is one of the World's largest 3rd party logistics providers, employing over 16,000 people and operating in over 80 countries. The findings highlight how, through decoupling various manufacturing and logistics processes, the company was able to improve customer service, increase productivity and free up capacity while positioning themselves as a key innovator in the industry.

Keywords: re-distributed manufacturing, re-shoring, globalization, supply chain management, supply chain design.

1. Introduction

It is becoming clear that competition is being driven to new levels in the third millennium. The forces that are driving this include factors such as the increasing globalisation of business, the adoption and exploitation of new technologies and the incessant demand for better and better values from customers. Among other factors they are producing conditions which encourage fitter supply solutions for the provision of products and services. In this era of what could be termed hyper-competition, a key question being faced by supplying actors in many sectors surrounds the design of the SC. This is a dynamic issue, meaning that solutions are continually evolving too. So the challenge of how best to get your SCs working so they optimise value delivery to market is an on-going quest being wrestled with by many organisations across numerous sectors around the world.

In addressing this, both academics and practitioners have increasingly reported on the global drive towards what has been termed *"re-distributed manufacturing"*, a move from centralized to distributed production and from global (offshored) to more local (near-shored) manufacturing. For example, the demand for more customised products and the impact of disruptive technologies, such as 3D printing, have led OEM to increasingly consider the final configuration of their products closer to the consumer. The reversal of previous decisions to offshore and / or centralise certain production activities is not a new phenomenon, however, and it has been documented since the eighties (Mouhoud, 2007). In spite of this, academic attention is lagging behind and research is characterised by the lack of a shared definition and full understanding of the factors driving this trend. This has limited the insights into the practicalities of designing and managing the emerging re-distributed manufacturing SCs

As such, the aim of this study is to attempt to clarify what re-distributed manufacturing is, to explore whether it is really a new concept or just a re-label of previous ones and to provide an illustration as to how the concept has successfully been applied in practice. Linked to this is the issue of the role logistics service providers may play in these re-formed SCs. Will they be side-lined, or could they elevate their positioning to perform more substantive roles for the benefit of themselves, shippers and consumers? A primary case study is presented highlighting the factors that drove the decision of a global electronics manufacturer to re-distribute its production activities, as well as the role that a logistics service provider played in designing and managing a re-distributed manufacturing SCs.

2. Re-distributed Manufacturing – A Literature Review

The concept of distributed manufacturing, also referred to as distributed production (Leitao and Restivo, 2000) or simply local manufacturing, is not new. Its primary attribute is viewed as the ability to create value at geographically dispersed manufacturing locations situated in closer proximity to the final customer (Ko et al., 2010). The resulting distributed production networks are, arguably, organizational structures more able to match both the speed and the efficiency necessary to compete in the global market. In this context, *re-distributed manufacturing* mainly refers to the reversal of a previous decision to centralise certain production activities at various global locations and focus on performing final value adding production activities closer to the consumer market, a trend increasingly evidenced in a variety of sectors, from electronics to fashion.

Various factors triggering this change have been mentioned by both academics (i.e. Ellram et al., 2013) and practitioners, such as:

- Changes in global SC costs structures (labor, transportation, firm productivity, raw material costs, etc.) – a key aspect here for the argument of re-distributed manufacturing is the avoidance of hidden costs and risks that can emerge in long SCs. For example, shipping costs are minimized when products are built geographically closer to their intended markets;
- Availability of materials and energy;
- The need for sustainable production systems – initial life cycle analysis indicates that (re-)distributed production can have a smaller impact on the environment and is more sustainable in long term than conventional manufacturing and shipping, mainly because of reductions in transportation embodied energy;
- Ever shorter product life cycles - the globalization of production resources, increased levels of competition, etc. have shifted the focus of industrial companies from the primary control of resources to a customer-centered control of time-to-serve. In addition, the speed of innovation in some sectors, such as technology, means there are very short selling seasons before products become obsolete. Shorter SCs are called upon as a result, which as well as reducing time to market, also reduce transportation costs and inventory as well as minimizing obsoletion impacts;
- Increasing demand for customized products and services - the demand for new innovations and customized products is leading to shorter product life cycles and a need for smaller, more frequent order quantitates. As a result, products manufactured

in facilities distributed across the globe, each serving a smaller area, can be customized with details adapted to individual or regional tastes;

- The increased availability and cost of small-scale equipment – i.e. flexible manufacturing systems, 3D printing, etc.;
- Easier access to information, enabling better communication and coordination in complex SCs systems;
- SC disruptions – SCs that stretch half way around the world are more likely to be disrupted by natural disasters, making them more volatile to disruptions;
- Intangible factors such as the marketing power of the 'made in…' label, which encourages local production.

In view of the aspects highlighted above, the debate around the fact that the phenomenon of re-distributed manufacturing networks is the direct and short term consequence of the global economic crisis and of government incentives to bring jobs back (Fratocchi et al., 2014) appears very myopic. The global scale of the phenomenon and its presence also in those countries where no government incentives are offered (Kinkel, 2012) suggest that complex dynamics involving locational, industry and firm-level factors require closer investigation in this context (Fratocchi et al., 2014). These changes are, in turn, leading to the development of new business models and SCs that require closer academic enquiry.

Several academic literature streams can be called upon in order to provide a theoretical background for exploring the re-distributed manufacturing trend, seen as a move back from globally centralised manufacturing to more distributed, localised production, situated closer to the end consumer:

- centralised versus distributed manufacturing;
- postponement / leagility;
- global versus domestic sourcing;
- re-shoring.

2.1. Centralised versus distributed manufacturing

Some of the research arguing for a move away from centralised resource allocation and order fulfilment towards decentralised decision making can be traced back to the 1980s, when the introduction of flexible manufacturing systems called for a new control paradigm (Dekkers, 2009). In this respect, networks of loosely connected, geographically dispersed industrial units were proposed as a potential solution to the increasing demands for flexibility and customisation (Dekkers and van Luttervelt, 2006). Later, the term 'distributed manufacturing' came to include the virtual manufacturing of products crossing the borders of a monolithic company (van Brussel et al., 1998; Leitao and Restivo, 2000). However, most of the research in this area focused on the information technology and related computer applications enabling the control of independent units. A parallel stream of research, however, focused on what was termed "postponement" strategies, which argue that achieving greater customization of products in a cost efficient manner calls for early-stage production processes to be more concentrated, while late-stage processes more diffused.

2.2. Postponement

The concept of postponement (or delayed product differentiation) was originally introduced by Alderson (1950) and later expanded by Bucklin (1965). The basic logic of postponement is that differentiation of goods (in terms of form, place and / or time) occurs during manufacturing and logistics operations situated further downstream in the SC. Bucklin (1965) stated that savings in costs related to uncertainty would be achieved by moving product differentiation nearer to the time of purchase, where demand is likely to be more predictable. Postponement strategies also offer the potential to reduce risks arising from market uncertainties, mainly associated to inventory holding of finished goods. Johnson and Anderson (2000) found that this strategy is particularly valuable for managing short-life products.

However, the benefits of postponement must be balanced against other costs arising in the channel, such as the risk of lost sales. The concept of speculation, the opposite concept of postponement, holds that “changes in form and the movement of goods to forward inventories should be made at the earliest possible time in the marketing flow to reduce the costs of the marketing system” (Bucklin, 1965). Speculation makes it possible to gain economies of scale in manufacturing and logistics operations, reduces the costs of sorting and transportation, and limits the number of stock outs.

The system of practices (or supply chain management paradigm) mostly associated with the implementation of the postponement strategy in the SC is that of leagility. The leagility concept, originally developed by Naylor et al. (1999), aimed to leverage synergies in the lean and agile paradigms, through their decoupling via strategic use of stock in the product delivery process, specifically in a manufacturing context. Naylor et al. (1999) further highlighted how the best of both worlds could be achieved by the prudent integration of the two concepts in order to develop what they ultimately decided to call ‘leagility’. Using a personal computer SC as an example, the concepts of decoupling and postponement were utilised as means through which the two different strategies could be combined. The processes upstream of the decoupling point were characterised as lean and those downstream as agile. The general applicability of the concept was illustrated by making reference to generic strategic models of SCs such as make-to-order, make-to-stock and assemble-to-order.

Furthermore, in order to minimize the leannes/agility trade-offs, many firms are also combining global and domestic sourcing in the design of their SCs. In mixing domestic and global sourcing to reach the optimum set of outcomes, various factors to be considered have been suggested: the level of demand uncertainty, availability of information and manufacturing technology, accessibility of local subcontractor clusters and development of long-term relationships with subcontractors (Purvis et al, 2014).

2.3. Global versus local sourcing

There is a vast amount of literature focusing on the advantages and disadvantages of global versus domestic sourcing. Global sourcing practices, for example, have been linked to the speculation concept, securing products at the earliest possible time and holding inventories until the products are sold to retailers. In a similar context, domestic sourcing is related to the postponement principle. That is, the delay in product differentiation happens nearer to the retailers' selling point. While global sourcing lowers production costs, mainly through low wages/employment costs and economies of scale, this advantage needs to be justified to the extent that the extra inventory-holding cost and delay in time-to-serve is acceptable. However, due to the high demand uncertainty characteristic of industries such as apparel and electronics manufacturing, holding of speculative inventories, especially in the form of finished goods, may incur significant loss of profits. Global sourcing may also result in poor customer service due to slow or lack of replenishment (Jin, 2004). On the other side, domestic sourcing can lower inventory costs and increase customer service by reducing the time-to-serve and improving replenishment rates, but it can incur higher production costs (Chopra, 2003). At the same time, the decision to manufacture closer or further to the headquarter and / or the customer needs to be continuously reconsidered, as the balance of costs and time to market can change dramatically at very short notice, calling for the re-design of the SC and the re-distribution of production activities across the world (Handfield and Nichols, 2002; Lee, 2004).

2.4. Re-shoring and near-shoring

Recently, both academics and practitioners have been reporting on the trend of re-shoring, also referred to as back-shoring (Kinkel, 2012). Hagerty (2012), for example, associates re-shoring to 'bringing manufacturing back-home'. This denotes a generic change of location with respect to a previous off-shore country (Fratocchi et al., 2014). In this context, Ellram et al. (2013) distinguish between offshoring, which refers to the locating of a manufacturing facility outside of the company's headquarters region, whereas near-shoring refers to locating a manufacturing plant within one's region.

For example, companies such as Apple and Motorola have received increased media attention in relation to their decision to target the American market with products manufactured in the USA, such as the latest Mac Pro and the Moto X, respectively. In the same context, the Chinese computer maker Lenovo has announced rolling out their ThinkPads laptops and desktop computers for the USA market, which will be produced at their new North Carolina plant. Lenovo, however, will carry on producing the same products at various other global locations, while their decision to manufacture in the USA for the USA market can, arguably, be called further- rather than near-shoring. This is mainly due to the fact that the extant literature surrounding the concept of re- or near-shoring mainly refers to a reversal of a previous decision to offshore production activities in relation to the company's headquarters, rather than the consumer market, such as the case of Lenovo.

Gray et al. (2013) further highlight that the "re-shoring" term is agnostic as to whether the manufacturing being brought home occurred in a wholly owned facility in an offshore location or in the factory of an offshore supplier. For example, Fratocchi et al. (2014) argues that re-shoring is fundamentally concerned with where manufacturing activities are to be performed, but should not be viewed independently of who is performing the manufacturing activities in question. In our study, one of the aims is to address the debate of whether the re-distributed manufacturing model should be perceived as a sole decision to relocate, or also an ownership model.

2.5. Re-distributed manufacturing – A location and ownership decision

Though various streams of literature, highlighted in the previous sections, have been identified as a base for looking for driving factors, models and tools to adequately address various challenges of designing and managing re-distributed manufacturing SCs, there is currently no academic research aimed at either defining this new emerging concept or providing empirical evidence as to how it can successfully be implemented in practice.

First, we believe that one of the first assertions that needs to be made with regards to attempting to clarify any misconceptions related to the re-distributed manufacturing concept is that, for re-distributed manufacturing to occur, a choice of pursuing centralised manufacturing must have been made in the past, regardless as to where the centralised activity was performed. As such, re-distributed manufacturing does not imply a 'simple' change in manufacturing location, but a fundamental reconsideration of the scale and location of the operation in regards to the targeted market (a shift from a few large, centralised activities to many small, decentralised ones located closer to the point of consumption). Thus, what we perceive that makes the re-distributed manufacturing phenomenon a potentially fertile ground for academic research is the fact that it is not just a location decision, but requires a fundamental reconsideration of the design and management of end-to-end SCs.

Furthermore, we argue here that while the driving factor for firms to consider the re-distribution of their manufacturing facilities is the reduction in time to market, various other factors need to be considered, when seeing this as a location decision, such as country-specific advantages (Dunning, 1980; Rugman, 1981), tax rates, tariffs, wage rates and employment legislation, energy costs, availability of resources, currency exchange rates, regional level of risk (i.e. intellectual property risk, currency risk, etc.), cultural differences, etc.. The decision as to then maintain these activities in-house or outsource is also affected by a series of factors which are well documented in the outsourcing vs. insourcing (or make vs. buy) academic literature.

As such, a comparative analysis of the relevant literature streams highlighted in the previous sections, which enabled us to capture different features of a potentially emerging concept, leads to the following characterisation of re-distributed manufacturing as a standalone paradigm:
- It is a reverse decision with respect to a previous one to centralise manufacturing at a certain global location;
- The driving factor is reduction of time to market, but various other aspects need to be considered as enablers;
- It involves the re-design of certain downstream parts of the SC, which leads to the re-location of final production facilities closer to the consumer market;
- It should be perceived as a decision to relocate but also potentially an ownership model (in-sourced or outsourced), as it calls for the development of new core capabilities.

Table 1 sets out a high level summary of alternatives:

	Centralised	**Re-distributed**
Outsourced	Outsourced Centralised Manufacturing	Outsourced Re-distributed Manufacturing
In-house	In-house Centralised Manufacturing	In-house Re-distributed Manufacturing

Table 1. A conceptualisation of the centralised v decentralised manufacturing debate with the extra variation of the "make or buy" dimension (i.e. in-house or outsourced provision)

- In-house centralised manufacturing – a firm fulfils demand for all its markets from a centralised, wholly owned facility;
- Outsourced centralised manufacturing - a firm fulfils demand for all its markets from a centralised, outsourced facility;

- In-house re-distributed manufacturing – in order to fulfil demand for its targeted markets a firm relocates manufacturing activities closer to each targeted market, in wholly owned facilities;
- Outsourced re-distributed manufacturing – in order to fulfil demand for its targeted markets a firm relocates manufacturing activities to current / new suppliers closer to each of the targeted markets.

In summary, the factors that influence the decision for OEM organisations in many industries in positioning themselves in the medium-term on Table 1 appear to be shifting. Secondly, if it is a fact that this is leading to a shift in SC design towards more re-distributed manufacture in some cases, how and who does this impact? In particular, the previous clear delineation of production and outbound logistics activities becomes blurred in re-distributed manufacture with some of the production tasks clearly being deferred, occurring closer to the customer marketplace. Does this provide an opportunity or threat for the incumbent logistics providers?

2.6. The Potential Role of the Logistics Service Provider (LSP) in Re-distributed Manufacture

The development of decentralised manufacturing through concepts such as re-distributed manufacturing are potentially a demand-side game changer for providers of logistics services – the LSPs. The need for change in LSPs are, however, also being fuelled by supply-side changes which are worth reflecting on too as they are pertinent to the background to this research.

Logistics is one of the most common outsourced activities. This has resulted in the development and growth of the logistics service industry with logistics companies performing a whole range of services under the broad logistics service provision banner, from core logistics activities such as basic transportation and warehousing or freight forwarding and other tasks to an emerging demand for more advanced logistics services (Hertz and Alfredsson, 2003).

One of the issues, however, has been the commoditisation of the more core logistics activities. Few barriers to entry combined with the fact that many of the more traditional logistics service providers, known as 3PLs, find it hard to differentiate themselves in their marketplace have led to a characterising feature of very small margins in terms of returns on operations and investments (Vasiliauskas and Jakubauskas, 2007). This had negative impacts on the customers for logistic services too, who are concerned by, for example, the lack of innovation in logistics matters (Cui et al. 2009). As a result, there is a level of dissatisfaction form both sides – the LSPs and their shipper customers.

One solution that has been identified by some innovative players in the logistics market is to boldly re-define the role that could be played by LSPs in modern global SCs. The future focus should be on the need for end to end process excellence in the SC: “3PL companies are playing ever increasing roles in extended SCs, transforming from movers of goods to strategic value-added entities” (Jayaram and Tan, 2012).

In some ways this is similar to the idea of the SC orchestrator, or the 4PL concept coined in the mid-1990s. The 4PL was defined as “an integrator that assembles the resources, capabilities and technology of its own organisation and other organisations to design, build and run comprehensive SC solutions” (Bumstead and Cannons, 2002). The idea of the 4PL centres around the thinking that an organisation can act as an overseer of the SC, minimising its own risks by not actually undertaking any SC activity by itself, but at the same time holding accountability for end to end SC performance through the delegation via outsourcing of the range of activities that occur along the SC. Using advances in technology to interface with the SC actors performing the tasks the idea is that the 4PL can take an overview position, with the objective of better optimising the holistic SC process by removing duplication, encouraging an integration of activities and pursuing a more synchronised chain of supply.

There is though a great deal of competition (to the 3PL extending its role to a 4PL position) from different types of organisations to take up this role. For example, liner shipping companies may feel that as they control one of the key driving elements of the international SC, the movement of goods between ports, they are best placed to provide an end to end solution to shippers. Alternatively, port operators, freight forwarders, retailers or OEM manufactures may also see themselves fulfilling this extended role. No clear consensus has emerged in this area as to what type of organisation is best equipped to take this more extended SC role.

From the LSP/freight forwarder perspective it may be the strategic need to develop their services into more lucrative, more longer lasting business relations with shippers combined with their knowledge of the logistics marketplace and their base relation with shipper clients that may mean they are best suited to fulfil this position. In addition, as tasks are "re-distributed" along the SC this may suit logistics operators who are better used than other SC players at managing decentralised activities, it could be argued.

So a further adaptation to the 4PL idea is where a logistics player in the SC, who does have a "doing" role already, and has added on to this the wider orchestrating role, also begins to carry out some additional value-adding tasks along the SC as well. An opportunity for this may well occur when manufacturing becomes more decentralised and thus logistics providers can use their position of working with the shipper and understanding the need for end to end SC solutions to also take on board re-distributed manufacturing as well.

Various research questions stem from this idea. For instance, what new demands does this place on the logistics provider? Does this change the nature of the relationship between the shipper and the LSP? What risks and opportunities does this present to both shippers and providers and does this impact on the logistics provider's basic business model and competitive position? In contributing to addressing these issues this study is not only interested in re-distributed manufacturing as an emerging concept, but also on the potentially changing role of logistics companies in such re-designed SCs.

3. Method

An in-depth, longitudinal case study approach is adopted in this research, with two of the authors of the paper embedded in the case company, the Panalpina Group, as Global Head of Business Improvement and Global Head of Logistics. The company is one of the world's leading providers of SC solutions. It combines its core products of Air Freight, Ocean Freight and Logistics to deliver globally integrated, tailor-made end-to-end solutions. The Panalpina Group employs around 16,000 people worldwide, operates a global network with some 500 offices in more than 80 countries and works with partner companies in a further 80 countries.

A longitudinal case study was used in this research with data spanning 3 years. The data was collected using unstructured and semi-structured interviews and verbal narratives, presentations, documentation and archival records in order to capture the company's journey towards developing an innovative solution for its main electronics manufacturing partner. The technology sector was chosen as it represents a highly dynamic and competitive industry. This forces participants to constantly re-evaluate their SC design and supply operations practice.

4. Case Study Findings

Panalpina's main expertise is in freight forwarding, with a long tradition of success in two core product offerings: Air freight and Ocean freight. In 2011 Panalpina decided to expand its service offering by adding Logistics as a core product, giving its customers an end-to-end 3PL (Third Party Logistics) solution. To launch the new logistics product, a new team was recruited, investments in IT, tools and services were made and a new strategy was developed with a focus on the development of Logistics VAS (Value Added Services). By focusing on VAS, Panalpina deliberately set out to avoid using the traditional 3PL business model of building warehouses and offering basic storage and pallet moving services. From the beginning, the emphasis was on developing services that involved adding value to the customers' product through transformational activities.

As the logistics business became more successful, a larger team was recruited to expand the VAS offering. The recruitment was centred around skilled manufacturing managers with experience in Hi-Tech manufacturing, rather than managers with a freight or logistics background. This recruitment policy introduced a new skill-set into the organisation, both in terms of a deep understanding of current technology customers' SCs, but also in the principles of lean manufacturing. This new management team were the main drivers behind the development of Panalpina's new Logistics Manufacturing Services (LMS) concept.

At the opening of a new logistics facility for a major technology customer in Brazil, the Panalpina logistics team, drawing on the additional manufacturing skills recruited into the business, identified the opportunity to completely re-design the traditional technology SC model for their customer. This was the inception of the new LMS model.

4.1. The Traditional Supply Chain Model

The SC model traditionally employed in the technology sector originally emerged due to the availability of low cost labour in certain countries, most notably in China. As manufacturers moved to these countries, material and component suppliers also moved to these locations. This created a 'campus' mentality and an ever increasing centralisation of manufacturing in one location, usually the lowest labour cost location available.

One of the main characteristics of this SC model is a clear division between manufacturing and logistics. Typically, nearly all of the manufacturing process, from surface mount (SMT) or complete Knock Down (CKD), through assembly, configuration and FAT (final assembly and test) are carried out in one large manufacturing location, which is often operated by an Electronic Manufacturer Supplier (EMS) or Original Design Manufacturer (ODM). Once FAT is complete and the final product configured, it is then sent to a logistics location, often operated by an LSP (Logistics Service Provider) for final pick, pack and delivery to the end customer. The typical split of manufacturing services (provided by EMS companies) and logistics services (provided by LSP companies) is visualised in the image below (Figure 1).

Some of the advantages of the traditional model are associated with the centralisation of all manufacturing in one location (often in a low cost labour location) and all finished goods in another (often closer to the end customer). However, manufacturers increasingly now need to be able to provide customers with the very latest hardware and software (which can change from one day to the next) and customise products and deliver them quickly once ordered in the most efficient manner. In this context, centralised global supply chain models do not appear to provide either the required speed to market, or the ability to reduce the risk of obsolescence.

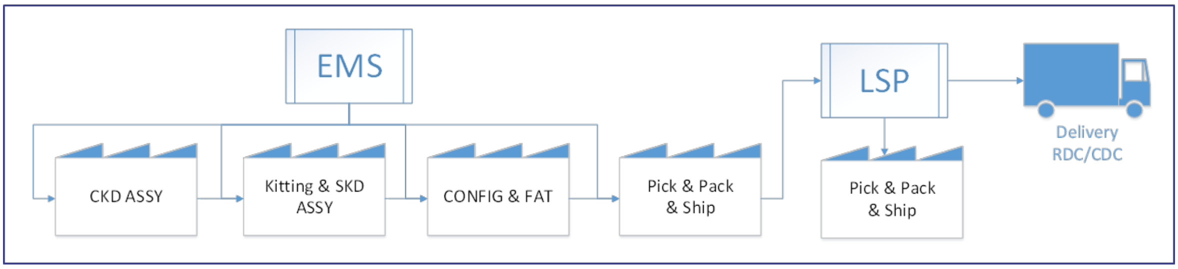

Figure 1. The Traditional Supply Chain Model in the Technology Sector

A typical example in the telecoms industry is in the configuration of base stations. In the traditional SC model, the software is uploaded onto a base station during the manufacturing process in China. By the time it has arrived at the customer in, say, Brazil, the software has already been updated and changed multiple times, making the product obsolete during the transportation phase from manufacturer to customer. These changes are occurring in a number of industries, but are particularly visible in the technology industry and have led Panalpina to conclude that fundamental shifts to international manufacturing and SCs are emerging, to which it needs to respond.

4.2. Macro-economic trends that are driving the changes to the traditional supply chain model.

One of the principle changes that Panalpina identified was an increased focus from their customers towards near shoring. This focus was being driven by both cost considerations and customer demands. The section below summarises the considerations that were driving the near shoring focus of its customers.

1. Cost considerations

Organisations were increasingly reviewing the true costs of moving manufacturing to low-cost labour locations. This review was driven by a number of secondary drivers.

- <u>Levelling of global labour costs & the impact of automation</u>

Although significant differences remain when comparing the hourly direct labour costs between high cost locations such as UK or USA, and lower cost locations in Asia, high inflation rates are quickly reducing this significance - in China for example, the annual inflation rate is 13%. More pressingly, organisations are finding that management costs in Asia are the same, if not higher, than in high cost countries due to the scarcity of experienced managers. When total labour costs (operators plus management) are considered and inflation factored in, the true benefits of moving all manufacturing to one large location in a low cost country can be negligible. Furthermore, with increased levels of automation in manufacturing processes, the relative importance of labour costs is also decreasing.

- Levelling of energy costs

As well as labour, the impact of energy costs has become less of a concern when selecting manufacturing locations. For example, the price of natural gas in the United States has fallen by two-thirds since 2007. The result is that the energy costs of manufacturing in USA are similar to those in Asia.

- Increased Political and government subsidies

In recent years, there has been an increase in political and government subsidies to encourage manufacturers to re-locate to UK, USA and traditional high cost manufacturing locations. When these subsidies are also considered, the true cost of operating in a high labour cost versus a low labour cost location can be minimal.

2. Increased risk of supply chain disruption

Another risk of having all manufacturing in one location and far from customer demand is the commercial impact if the SC is disrupted. Recent political instabilities (such as riots, terrorist attacks or embargos) or environmental catastrophes (such as tsunamis or earthquakes) have also prompted organisations from Panalpina's SC to rethink the risks to their business if they are reliant on a small number of manufacturing facilities that are far from customer demand.

3. Competitive landscapes

As information, ideas and technologies are more quickly developed and brought to market (examples include additive manufacturing, nanotechnology, advances in power supply technology), smaller, more specialised manufacturers are able to challenge larger technology organisations with innovative technology and manufacturing processes. The only way for technology manufacturers to remain competitive is by designing a SC model that allows them to integrate the latest technologies and software as close to the customer demand as possible.

4. Customer demands

Perhaps even more importantly than cost considerations or competitor landscape shifts, changing customer demands are making the traditional SC model increasingly unsuitable. In today's market, with the ubiquitous access to information about product releases and new versions, customers demand instant access to the latest technologies, both in terms of hardware and software. An organisation that can deliver the same product in one week, when their competition can deliver it in one day, is unlikely to survive in today's market.

4.3 The Logistics Manufacturing Service

In view of the macro-economic forces described above, Panalpina, together with one of its major technology customers, developed a new Supply Chain model, The Logistics Manufacturing Service (LMS), as seen in Figure 2. In this new model, rather than centralising production in one location, manufacturing is decoupled into various stages with the aim of postponing as many manufacturing operations as late as possible in the SC, as close to the end user as possible. What differentiates this model from a more 'traditional' SC that adopts a postponement strategy is the fact that only the CKD activity is carried out in the customer's central manufacturing location. The remaining core manufacturing processes, typically the specialism of EMC companies, such as box build, kitting, configuration, FAT (final assembly and testing) are carried out by Panalpina in a logistics facility located in Brasil.

The new model had a major impact on the customer's SC:

1. Because products are held in a semi-assembled state, closer to the customer demand point, the overall lead time for customer orders has reduced from 90 to 15 days;
2. As a result of shorter lead times, on time delivery has improved from 20% to 99.97%;
3. As there is less push of inventory into the logistics facility, inventory accuracy has improved from 15% to 100%;
4. As quality control is built into the process and carried out at the last possible point before delivery to the customers, Outbound Quality Control failure rate has reduced from 11.6% to 0.5%;
5. Because labour can be shared between the manufacturing and logistics activities, providing the operation with increased flexibility and flow, overall productivity at the site has improved by 110%;
6. As products are configured and built at the last possible moment before delivery, there is less opportunity for customer requirements to change, resulting in obsolete configurations and wasted materials. As a result of the changes, cabling material scrap costs have reduced by 20%.

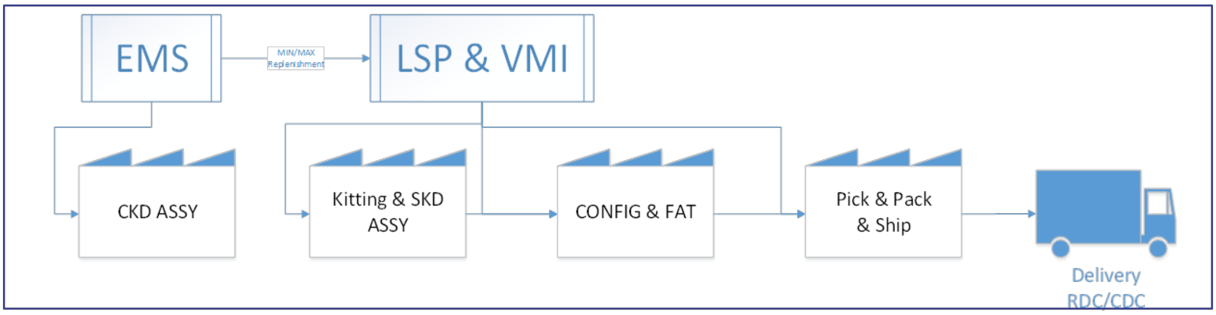

Figure 2. The New LMS Supply Chain Model in the Technology Sector

5. Analysis

Based on the case study findings presented above, the operational changes and improvements made by Panalpina to set-up the LMS model are summarised in the table below:

Traditional supply chain model	LMS Model
- Manufacturing processes and logistics processes carried out independently and as two separate operations, with 100% of manufacturing processes carried out in manufacturing facility; - Manufacturing usually carried out in low cost geographies (such as China, India).	- Manufacturing processes combined and integrated with logistics processes; - Final assembly and logistics processes carried out within the logistics facility; - Manufacturing carried out as close as possible to customer demand points.
- Build to stock processes (products pushed from manufacturing).	- Products stored in semi-knock down state and pulled at the demand of the customer.
- Planning and scheduling defined and pushed by manufacturing	- Planning and scheduling carried out by LMS team, planned based on customer

processes; - Logistics functions work on traditional productivity measures, with a focus on keeping everyone busy.	demand rather than manufacturing output; - New lean concepts are used, with a focus on capacity and bottle neck management and the application of the theory of constraints;
- Separate manufacturing and logistics KPI's.	- LMS KPIs defined, covering both logistics and manufacturing processes.
- Product quality checks carried out at manufacturing plant.	- Product quality is built into the final assembly process, ensuring final checks are carried out as close as possible to final customer delivery.
- Most recent software uploaded at manufacturing plant.	- Most recent software uploaded at logistics facility, ensuing more recent software uploaded before delivery to customer.
- Customer configurations carried out at manufacturing plant. This can often result in customer requesting changes to the configuration after the product has left the manufacturing facility. In this case, the product needs to return to manufacturing to be re-configured or specialists from the manufacturing plant need to travel to the logistics facility to carry out the configurations.	- Customer configurations carried out at logistics facility. The result is that customer configurations are carried out much closer to the point of customer demand, resulting in a much lower probability that configurations will change between order and delivery.
- High levels of working capital.	- Decreased working capital, as value is not added to the product until later in the SC; - Product held as components not as finished inventory, further reducing working capital.
- Standard returns process, where products are returned to manufacturing plant or separate repair centre.	- Returns can be repaired directly at the logistics facility, or des-assembled to go back into the manufacturing process.
- Spare parts inventory held separately in manufacturing plant and in spare parts field.	- Spare parts inventory and manufacturing supplies combined at the logistics facility to reduce overall inventory levels.

Table 3. Operating changes before and after the introduction of LMS

The changes highlighted above emphasise that, in the new re-distributed SC, the LSP was perceived as better positioned to manage decentralised, final assembly activities in the local consumer markets. This enabled Panalpina to develop their services into more lucrative, longer lasting business relations with shippers as they begun to carry out some additional value-adding tasks along the SC.

In our earlier literature review section, we proposed 4 features of the potentially emerging concept of re-distributed manufacturing. The case study findings presented above enabled us to seek further evidence with regards to the relevance of these features in practice:

Re-distributed manufacturing features	Evidence from case study
- It is a reverse decision with respect to a previous one to centralise manufacturing at a certain global location	- The new LMS model proposed by Panalpina meant that its customer only needed to maintain core CKD activities at a central manufacturing location in China, with subsequent manufacturing activities being moved to Panalpina's facility in Brazil, closer to the final customer. As such, advantages of both centralised and decentralised production are maintained.
- The driving factor is reduction of time to market, but various other aspects need to be considered as enablers	- Time to market was cited by Panalpina as the main driving factor. However, other drivers were highlighted, such as cost considerations (levelling of global labour costs and the impact of automation; levelling of energy costs; increased political and government subsidies); increased risks of SC disruption; a new competitive landscape; changing customer demands
- It involves the re-design of certain downstream parts of the SC, which leads to the re-location of final production facilities closer to the consumer market	- As highlighted in Figures 1 and 2, the manufacturer's kitting & SKD assembly, configuration & FAT and the pick 7 pack & ship activities were decoupled from the CKD assembly and performed at a different facility in Brasil
- It should be perceived as a decision to relocate but also potentially an ownership model (in-sourced or outsourced), as it calls for the development of new core capabilities.	- The resulting set of decoupled activities (kitting & SKD assembly, configuration & FAT and the pick 7 pack & ship) have been relocated to Panalpina's facility in Brasil, who now manage them on the customer's behalf. This meant that Panalpina needed to develop new manufacturing and SCM capabilities, which it hopes that it can then deploy across other value streams.

Table 4. A review of the principal case study findings in relation to the literature on re-distributed manufacturing

5.1 Further potential for improvements and the future direction of LMS

Even though the changes made so far have made dramatic improvements to overall SC performance, Panalpina believe the re-distributed manufacturing concept has the potential to bring further changes to SC design, both in the technology sector and in other sectors, such as:

- Innovations and investment in micro-manufacturing technologies, such as additive printing, can now allow parts to be manufactured directly in the logistics facility. This will mean that a higher proportion of manufacturing could move into the logistics facilities;
- The new model enabled Panalpina to gain increased visibility along the value stream, including BOM details, detailed order profiles and return and repair flows. As a result, Panalpina is now in a position to provide more advanced forecasting solutions to its customers;
- Integration of LMS activities with repair and return activities. Panalpina have recently established a repair and return centre inside their LMS facility. The benefit is that repairs can be carried out in the logistics facility (rather than shipping back to a central manufacturing plant) and also parts and components from the LMS activities can be used in repair processes – reducing the overall inventory required;_
- Integration of LMS activities with spare parts activities. Similarly, as components are stored in the LMS facility rather than at the manufacturing facility, there is more opportunity to share inventories with spare parts inventories;
- An opportunity for multi-customer LMS shared facilities now exists, where industry common manufacturing activities (cable cutting, configuration, testing) can be carried out for more than one customer in one LMS facility. This would reduce costs but also encourage knowledge sharing across various value streams;
- Local procurement opportunities have now opened up, as components will be manufactured close to customer demand. This will further reduce inventory levels (as components will be stored closer to customer demand) and increase speed to market.
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The emerging changes to the traditional SC model ae summarised below in Figure 3.

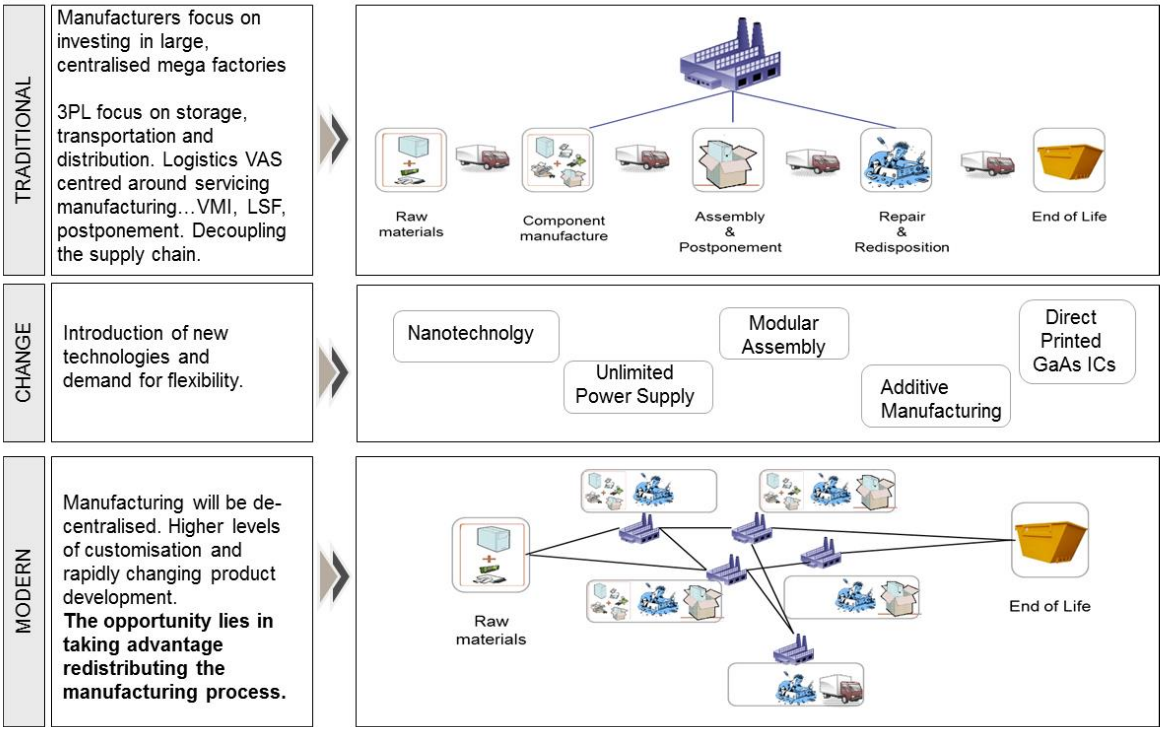

Figure 3. The Changing Nature of Global Supply Chains in the Technology Sector and the Changing Role LSPs can play in them

Panalpina are already working on ways to integrate these ideas in other sectors, such as fashion, where product life cycles are also drastically reducing, and the requirement for personalised products is perhaps even higher than in the technology sector.

6. Conclusions - The Future of Re-distributed Supply Chains

Although the case study presented above has focused on the technology sector, the literature review introduced at the beginning of the article indicates that a wider industrial change is occurring, with more fragmented SC models emerging, in which stages of manufacturing that traditionally occurred in one location are now re-distributed around the world. For logistics companies, this change provides both a threat and an opportunity. The opportunity is that, unlike EMS companies, they already have a large internationally dispersed footprint of facilities ideally located to manufacture products close to customer demand. Logistics companies can use this global footprint to begin to offer these niche manufacturing services to their shippers, combining them with their already existing logistics services.

However, one result of these changes will be an increase in the importance of information management in coordinating the resulting globally re-distributed SCs. It is also important to stress here that in these SCs of the future, organisations should not assume that they can simply re-design their production networks and move their manufacturing plants around the world as structural supply and demand changes occur. To benefit from these changes, organisations must acknowledge and embrace a new type of re-distributed manufacturing, one in which specialist suppliers will need to co-operate and compete in a decoupled SC.

At the same time, the new LMS concept also has the potential to threaten the existing business model of companies providing traditional logistics solutions, where a large proportion of revenues are generated by freighting products from low cost locations and storing them in warehouses close to high income markets. In the future, with international flows from Asia to Europe and Americas expected to decrease, as manufacturing is moved closer to customer demand, the need for large inventories (and warehouses to store them) will reduce. Further research is required to assess the full uptake of the proposed concept of re-distributed manufacturing in practice, evaluate its main features and determine its long term sustainability.

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Smart Units in Distributed Manufacturing (DM) -Key Properties and Upcoming Abilities

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Abstract
Rapid developments in ICT totally reshape manufacturing as machines, objects and equipment on the shopfloors will be smart and online. Interactions between virtualisations and models of manufacturing units will appear exactly as interactions with the units itself. These virtualisations may be driven by providers with novel ICT services on demand that might jeopardise even well established business models. Context aware equipment, autonomous orders, scalable machine capacity or networkable manufacturing unit will be the terminology to get familiar with in manufacturing and manufacturing management. Such newly appearing smart abilities with impact on network behaviour, collaboration procedures and human resource development will make distributed manufacturing a preferred model to produce.

Keywords: virtualisation, networkability, autonomous unit, smart manufacturing

1. Introduction

The convergence of intelligent devices, intelligent networks and intelligent decisions will enable information integration to support agile networks, real-time monitoring and controlling of manufacturing plants and assets and rapid customization and realization of products. Smart processes, further enabled by advanced software support and digital technologies, will continue to alter the productivity and quality of production processes for many decades to come (Deloitte, 2012). In DM[1], smart processes are driven by networks of smart manufacturing units. These units are expected to be context-aware and predictive with the ability to make decisions for diagnosis, for prognosis and for optimal performance.
Ubiquitous Computing (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). This 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 computing is a novel model for enabling ubiquitous computing, a 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 multiplied and released with minimal management effort by service provider interaction (NIST, 2011). A cloud is a type of parallel 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

[1] Distributed manufacturing is a manufacturing network whose functionality and performance is independent of the physical distance between the involved units and elements.
This includes logical and spatial dispersed units which cooperate and communicate over processes and networks in order to achieve manufacturing functions (Kuehnle, 2010).

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, cloud ERPs and Cloud Manufacturing is already propagated, specifying a new mode of intelligent manufacturing which may become a networked 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 services resource virtualization in CM (Ming & Chunyang, 2013). 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. 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).
All cloud solutions enable to dynamically adapt in order to satisfy unpredictable or unexpected demand. The manufacturing cloud service can offer rapid scalability at all levels, e.g. manufacturing cells, general purpose machine tools, and standardized machine components (Wu et al., 2013)[2].
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 the complexity of determining how to allocate tasks and processes across these different environments (Macia-Perez et al., 2012).
Computer scientist had come up with the Internet of Things (IoT) in the context of ERA (EU). IoT technologies are already used to access and to connect manufacturing resources. The IoT can 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 [3]. In industry, the "thing" may typically be the product itself, the equipment, the transportation means, etc. 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, Kortuem u.a., 2010). For general use, a Smart Object (SO) is an autonomous physical/digital object augmented with sensing, processing, and network capabilities[4]. In contrast to RFID tags, SOs carry chunks of application logic that let them make sense of their local situation

[2] 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). Manufacturing resource description is done via the encapsulation of manufacturing resources. 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.
[3] 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).
[4] 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.

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).
Additionally pervasive computing has migrated from desktops to micro devices, and embedded computing is increasingly integrated into various kinds of objects. Significant progress has been made in many domains, such as machine-to-machine (M2M) communications, using wireless sensor networks (WSNs), ZigBee[5] and wireless body area networks (WBAN) (Chen et al., 2011).Achievements refer to the communications among computers, embedded processors, smart sensors, smart actuators, and mobile terminal devices without or with limited human intervention (Wan et al., 2012). The rationale behind M2M communications is to generate more autonomous and intelligent applications by networking and interconnecting machines.
For manufacturing the Industrial Internet is a term coined by GE (GE, 2012) and refers to the convergence of intelligent devices, intelligent networks, and intelligent decisions., the Industrial Internet is creating the very foundation needed to make smart manufacturing possible by bringing together brilliant machines, analytics, and scalable software platforms to enable nearly instant person-to-person (P2P), person-to-machine (P2M resp HMI), and machine-to-machine (M2M) communication (Wan et al., 2013).
Some years ago, an object virtualization method has emerged, known as Cyber-Physical System (CPS), also DCPS if distributed), (Lee, 2008), meaning the integration of computing systems with physical processes and physical environments[6], (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). A When using CPS, components may adapt themselves automatically to the other components, which inevitably changes the way in which these CPPS-enabled components are designed and manufactured (VDI/VDE, 2013). 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).
According to European Telecommunications Standards Institute (ETSI), standardization plays an indispensable role in long term development of the M2M technology[7], too. The five elements' structure proposed by ETSI results in three interlinked domains, formed by an M2M area network and M2M gateway, communication network domain and 3G, (Lu et al., 2011). Fig 1 shows M2M architecture domains in health and home applications, the cutting edge of the developments.
As advanced control techniques, cloud computing, emerging network technologies, embedded systems, and WSNs are further upgraded, CPS may be seen as an evolution of M2M. Moreover, all other developments, be it IOT, SO or pervasive or UC seem to converge to CPS as the most comprehensive ability to bridge cyber manufacturing worlds to the physical world. For DM applications, these smart developments are anticipated by the more specific Cyber Physical Production Systems (CPPS), e.g. strongly propagated in the national funding scheme Industry 4.0 in Germany.

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[5] ZigBee Home Automation is the industry leading global standard helping to create smarter homes that enhance comfort, convenience, security and energy management for the consumer. It appears to be the technology of choice for world-leading service providers, installers and retailers, http://www.zigbee.org/.
[6] Cyber-Physical System (CPS) is a system of collaborating computational elements controlling physical entities.
[7] The applications of M2M communications extraordinarily depend on many technologies across multiple industries. The technical standardizations for M2M are proceeding in 3GPP, IEEE, TIA, and ETSI. The ETSI drafting standards for information and communications technologies considers an M2M network as a five-part structure http://www.etsi.org/website/homepage.aspx.
(1)Devices, usually are embedded in a smart device and reply to requests or sends data.
(2) Gateway, acts as an entrance to another network. It provides device inter-working and inter-connection.
(3) M2M area network, furnishes connection between all kinds of intelligent devices and gateways.
(4) Communication networks, achieve connections between gateways and applications.
(5) Applications and services pass data through various application services and are used by the specific business-processing engines. Software agents analyze data, take action and report data.

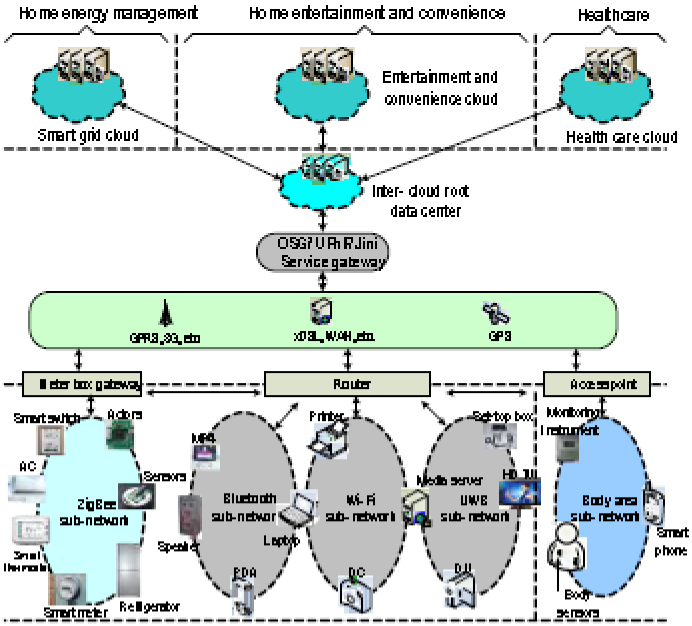

Figure 1: M2M Smart Grids advances in Healthcare according to Wan et al. 2013, as a blueprint for upcoming Smart Manufacturing networks

Cyber units may easily capture all functions a manufacturing unit may expose, as verified by the author for the control (MES) level (PABADIS'PROMISE), later for the factory and the field levels by atomising the automation pyramid levels (Fig. 2). Machines and devices including their controls are represented (emulation) by resource agents able to communicate and to negotiate (Peschke *et al.*, 2005). Standards as IEC 61804-3 specify the Electronic Device Description Language (EDDL) technology; AutomationML (Automation Markup Language), promoted by the author and his team has been approved as International Standard in June 2014 (IEC 62714-1), provides an open standard for suitable data formats in plant engineering information, based on XML.

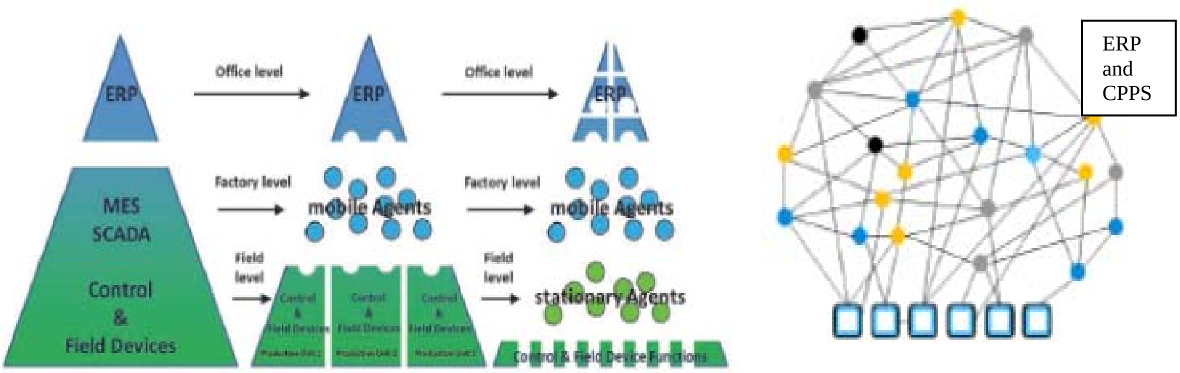

Figure 2: Progressing dissolution of level structures in Distributed Automation towards CPPS (according Peschke et al. 2006 and VDI/VDE 2013)

From the DM viewpoint, we rather see promising actions in choosing and selecting adequate devices for combining with manufacturing equipment or for upgrading manufacturing units. Moreover, progresses in WBAN have been extremely rapid, so many chapters even in most recent research concerning person-to-machine, P2M (respectively HMI) are obsolete already.

In manufacturing, disruptive innovations, as this next generation of ICT, meet strong resistance, as the protagonists are caught in path dependencies and strongly insist on pursuing the habitual innovation lines. However, it would be more successful to accept that innovations come from outside and to try to implement the most suitable ones instead of launching own initiatives for developing own specific smart manufacturing units.

All critical technologies for Smart DM are mature. Sensor and actuator networks, intelligent controls, planning models, plant performance optimization software, cyber-physical systems, security and other related devices are fully available on the market. Synthesized with model based engineering, systems integration technologies, open data analytics platforms, engineering information systems, and decision support methodologies at all levels, these devices are ready for use in DM.

2. Smart Manufacturing Units' Properties

As all smart units (Kawsar & Nakajima) manufacturing units, too, may be seen as specifications of the IoT and CPS. Manufacturing will increasingly appear as equipped by physical or/and digital objects, upgraded with sensing, processing, actuating and networking capabilities. Additional abilities, as environment-awareness or self-logging and self-reporting features further augment these objects and allow carrying many data about themselves as well as their activity domains. Moreover, smart units may make emerge network structures e.g. as results from their collaborative processes executed by manufacturing units striving for incentives (attractors). DM networks are being composed of self-optimising, self-orienting entities, managed as well as formed by defined rules. Network management establishes proper and genuine processes or initiates interactions, where units float within network configurations or collaborate and communicate on all levels of detail. Some configurations seem more favourable than others in some respect, so continuous monitoring has to evaluate for gradual and stepwise decisions or configuration alternatives; main issues are linking or detaching. In DM, business opportunities represent such governing "attractors", giving inputs to drive, to operate and restructure manufacturing networks to build up and to optimize versatile collaborative process nets.

3. Networkability

Smart units in DM have to exhibit strongest abilities to network. Networkability[8] may be seen as both, the internal and external ability of units to collaborate, simultaneously considering all manufacturing process relevant aspects (Oesterle et al., 2000). Networkability is defined at the DM network level by giving out the rules for alignments of network configuration at all levels of detail of units and subnets. Networkability may be supported by implementing coordination mechanisms that evolve interrelations between units towards networked organizations.

Networkability of smart units is enhanced by sensing and actuating technologies, which capture the global and the local contexts of products, objects, other units, and communication infrastructures, even IT models. In manufacturing, especially process and decision parameters are concerned with the aim of generating efficient processes, thus smart manufacturing units may even carry factory models, equipment geometries, process and task as well as interaction and decision models (Kuehnle, 2013).

In order to harmonise the networks on all LoDs, the models, attached to the network entities, should demonstrate fold and unfold properties that originate e.g. from encapsulated generics. For networks in manufacturing, aspect wise decompositions have already been successfully introduced as generic set up, distinguishing between aspects as information, organisation and processes similar to e.g. the specification of the CIM/ OSA framework and consecutive standards (Kosanke, 2006). Equivalent layer wise resource co-ordination schemes for networked manufacturing have also been successfully applied for enterprise units' networks

[8] Networkability of units may be measured both quantitatively and qualitatively for each of the above aspects. Quantitatively, networkability may be assessed by considering both time and costs, whilst qualitative analysis of networkability addresses the quality of change.

elsewhere [910] (Alt &Smits, 2007). Smart DM proposes the layer wise decomposition for fold and unfold generic to support networkability on all levels by keeping the aspects separate and tied together network wide at the same time, Fig. 3.

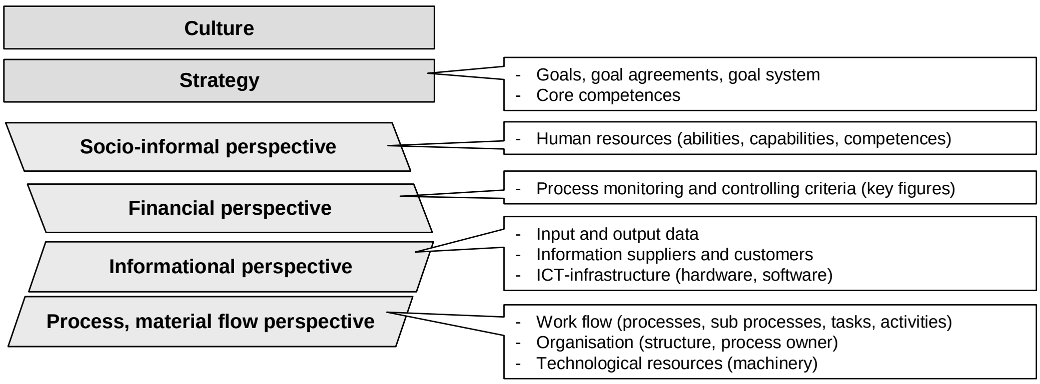

Figure 3: Process and manufacturing unit modelled by 6 layer descriptions

I. The culture layer envisions the network as a social system and captures the value and thinking pattern within the network. Consistent values are prerequisite for the networks' success.
II. The strategy layer describes the way, the network deals with the market and the resources. To quantify strategies, networks use objective systems, describing the actions of a network towards markets, economical pressure, and technological changes.
III. The social-informal layer models the HR and organisation contexts of the network. It includes all kinds of social and informal factors that determine and influence relationships within the network. Given that the network relies on autonomous units, teaming and communication skills' elements prove to be important.
IV. The financial layer deals with the evaluation of performance and the allocation of value addition across the network.
V. The information layer primarily addresses the design and handling of the flow of information. The major challenge is, to back up interconnections and re-configurability of devices or IT infrastructure. Smart units are equipped with computing units. Control systems are emulated using different networkable operating systems.
VI. The layer of process and material flow addresses the technical and physical side of the transformation steps. Technical function descriptions as well as logistics and materials handling are covered.

The layers culture and strategy may be considered as the 'umbrella' for all 4 resource layers. Dependent on the case and the level of detail to be addressed, fold and unfold properties are embedded to meet the corresponding levels of detail for communication between different

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[9] *Products and services. Networkability of products and services signifies their ability to be customized, and aggregated swiftly and with low barriers so that they are aligned to requirements in the network.
*Processes. Processes are critical building blocks of organizations. Networkability of processes implies that they may be synthesized quickly and with low costs to produce agile products and services.
∗Information systems. Networked information systems are required to be easily to be reconfigured to meet new and changing network requirements.
∗Employees. Employees are the linking pin in the networked organizations, gluing enterprises at the personal level.
∗Organizational structure. To be networkable, organizational structure needs to be able to morph dynamically to accommodate evolving, interconnected business processes.
∗Culture. Networkable culture refers to the culture-related ability of organizations to allow highly dynamic and trusted collaborations between partners in the network.
[10] 1. physical goods, 2. information, 3. people, and 4. Finances (Bartlett & Goshal, 2002)

entities. The layers also support the syntheses of network frameworks with specific priorities of aspects e.g. human centred team concepts or purely ICT driven units by layer-wise descriptions of interconnections of units, maintaining the complete aspect views throughout the entire networks on all levels of detail (Fig. 4).

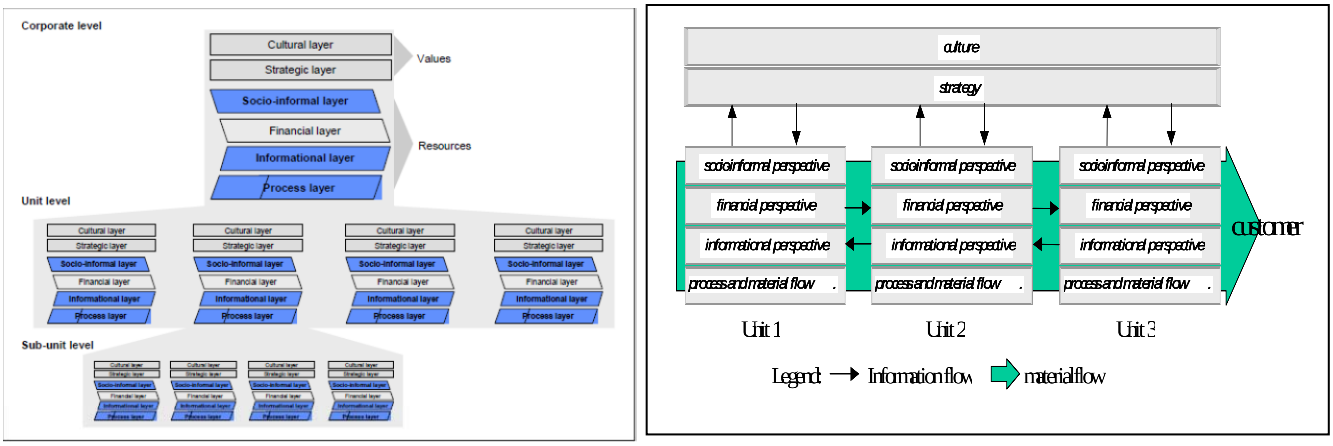

Figure 4: Generic Units' Layer model applied to Levels of Detail (Self-Similarity) and Networking (Layerwise Harmonisation)

In DM networkability of units has to promote the configuration of inter-unit collaborative processes on all layers. This includes the decision abilities, providing all procedures involved in governing and executing the necessary activities for (re)designing and setting up new or restructured processes. Processes in DM may be defined as an inter-related set of functions, ordered by precedence relationships, triggered by event(s) and producing observable results (Piedade et al. 2012).
Networkable decisions to be taken result in processes' configurations used as:

- descriptive mapping illustrating performed or running processes for analysing and extracting process parameters;
- prescriptive mapping, supplying anticipated process options for further evaluation and networks evolution and
- prospective instrument, displaying anticipated eventual configurations for simulation (which configurations should be preferred or avoided).

Activities and functions of the units may easily be structured according to the levels of detail, well differentiated according to the relevant network aspects. These generic models may as well be considered for process descriptions as they include the key constituents. They may be implemented according to the units' levels of detail and the units are assumed to organise tasks and activities respectively, Fig. 5. Orders, process segments and tasks may e.g. be executed via software agents[11].

[11] Groundbreaking work on this field has been done in international projects and by multinational consortia for establishing standards and for proposing theory that support distributed communication and decision making structures. Closest to the problem areas outlined here are the set ups of PABADIS and (GRACE, 2013). These approaches for Multi-Agent Systems (MAS) e.g. establish four types of agents, defined taking into consideration the process execution and as well as control the process segment specializations.

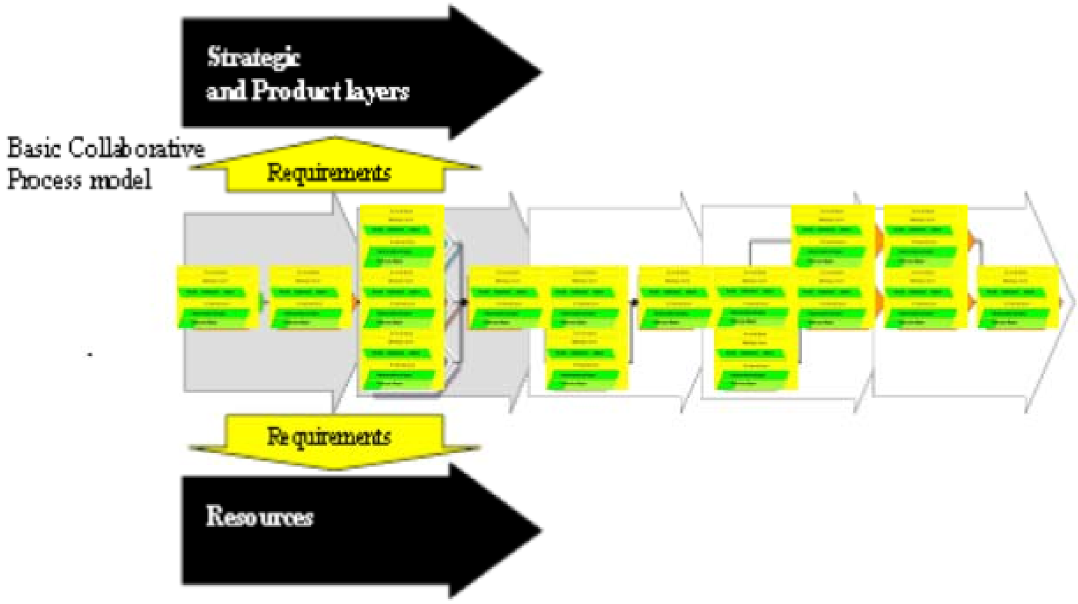

Figure 5: Basic Collaborative Process composed of Layer described Units

Based on the basic concept for the model the thematic approaches, i.e. product and resource, represented by agents, may be composed more detailed as a configured process network as results of agents interactions.
The introduced aspect layers of network ability do not only allow describing the units and prepare setups for interrelations. The layers also allow narrowing down a number of properties and smart manufacturing units are expected to exhibit in DM. These properties will not have to be newly engineered; it suffices to select and specify from the already existing devices.

4. Acceptance of existing Boundaries and Network Participation

Each smart manufacturing unit has to carry its digital presence, uniquely identified in the digital world, which includes ID and network interface address or other application-specific high level naming. Existing boundaries of the DM network must be accepted. This also affects the hierarchies of the (traditional) manufacturing systems in ERP, MES and shopfloor terms with clear responsibilities for factory equipment such as machines or factory sections. Smart manufacturing units should always retain its original functionalities and appearances, and maintenance should extend their physical usages so it is mandatory to decouple the augmented features from the original unit features. Smart units must support its original functions and properties, even if the augmented electronic cyber part is out of order. Moreover, the requiring interactions with smart units should be identical to the interactions with the original object. Mental models, cast into emulation that keep the instrumentation implicit (without additional interactions), will make humans commonly experience that they are dealing with the physical real objects rather than their digital abstract objects.

5. Context awareness

A smart unit is augmented with various technologies, thus it is expected that a smart unit is able of knowing its operational and situational states and should be able to describe itself. This awareness might be also be provided by a secondary infrastructure e.g. cloud. Awareness is generally defined as the ability to provide services with full awareness of the current execution environment. A definition is given by (Dey & Abowd, 2000) as any information that can be used to characterize the situation of entities (i.e. a person, place or object) that are considered relevant to the interaction, including the user and the applications themselves.

Aware units offer functionalities for gathering context data and adapting behaviour accordingly, aware systems, as cyber-physical systems, are by nature concurrent, as establishing and running processes are intrinsically concurrent and the coupling with computing shows concurrent composition of computing processes with the physical ones[12] by definition.
Using sensors and actuators, once recognised gaps and deviations may be stated and reconfigurations and adaptations may be initiated for determining current states of the models and vice versa, displayed effects may induce actions in the real world. Manufacturing information, which has been handed out as specs, work sheets, drawings, or schedule information, are now instantly and very precisely available enabling prompt identification, processing and communication of between actual and planned states and parameters.
To represent the current network states in a model system as well as to bring in modifications (e.g. for optimisation) from the model world into the real world, the different "network worlds" may be stored as models and gradually harmonized, so each action in the real manufacturing world may have an effect on the models and vice versa result in reactions towards the environment. Adequate set ups may be characterised as:

(1) A set of models that allow us to properly represent the context information at conceptual level. These models are capable to describe information related to objective fulfilment, position within the environment, location aspects and behaviour policies, as well as to the users that can interact with the system.
(2) Strategies and the decision procedures to allow the units to take adequate measures or to anticipate failures and to adapt the models according to new context data (Serral et al., 2008).

The set ups must as well depict a number of alternatives of possible states or configurations that might be chosen for further optimisation. However, history and time might keep from taking decisions in these directions and may therefore configurations be kept as future options. This notion of model thresholds is also called Dual Reality, (Schwartz et al., 2013) (possibly extended to multiple realities)); the "gradual iterative" decision mechanisms behind are outlined in (Kuehnle, 2013).

6. Heterogeneity

Heterogeneity of units is referred to as the properties of units being composed of diverse elements and using dissimilar constituents. In DM, heterogeneous manufacturing units and their constituents configure a networked and have to closely collaborate. Overcoming heterogeneity is a central issue in DM, as, due to the variety of devices and units involved, DM is intrinsically heterogeneous. The units or their constituents are to be connected and to configure networks comprising different types of computing units, potentially with vastly differing memory sizes, processing power, or basic software architecture. In DM, heterogeneity may therefore be assumed omnipresent, it occurs on all levels and for a number of reasons. On the informational side, heterogeneity may additionally come with different hardware platforms, operating systems, or programming languages. On the conceptual level, heterogeneity originates from different understandings and modelling principles for the same real-world phenomena.
Basically, two ways of coping with heterogeneous systems can be differentiated:
1. Establishing a comprehensive unified theory and

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[12] Accordingly, each of the aware manufacturing objects may carry a number of respective attributes classified into (Dey & Abowd, 2001):
identity (unique identifier),
location (geographic position, proximity etc.),
status (or activity) (intrinsic attributes of units, e.g., tool use, processes running etc.)
time (local time, timely priorities, ordering steps etc.).

2. Providing abstract data models and semantics.

In smart DM both directions are recognized. Inherent heterogeneity- and integration issues of different components as well as all challenges around are treated with novel unifying network and control theory (Kuehnle, 2013). The generic layer aspects of the introduced model definitely allow separating heterogeneous connectivity and collaboration issues as well as keep their break downs and fold ups. Therefore enabling interactions between sets of heterogeneous ICT devices of different brands and marks, i.e. interoperability, is conditio sine qua non in any DM scenario.
Moreover, heterogeneous networks require permanent revision of network components with emphasis on real-time operations requirements, so communication and sensing, actuating and processing in meshed control loops are supported.

7. Interoperability

The property of diverse systems and subsystems to work together (inter-operate) is referred to as interoperability. Interoperability is defined, as soon as operable units are available. Operability itself refers to the ability to safely and reliably run a system, in line with general and unit specific requirements. IEEE defines interoperability as the ability of two or more systems or components to exchange information and to use the information that has been exchanged. Interoperability can be understood as the capability of ICT systems as well as all supporting processes to exchange data as well as to allow sharing of information and knowledge.
Issues in collaboration and co-operation of units appear in larger contexts as communication between people, communication between people and ICTs and also between different ICTs. Consequently several levels of interoperability are differentiated. Furthermore, IEC TC 65/290/DC identifies levels of compatibility depending on the quality of communication and application features in a cumulative scale (Fig. 5).

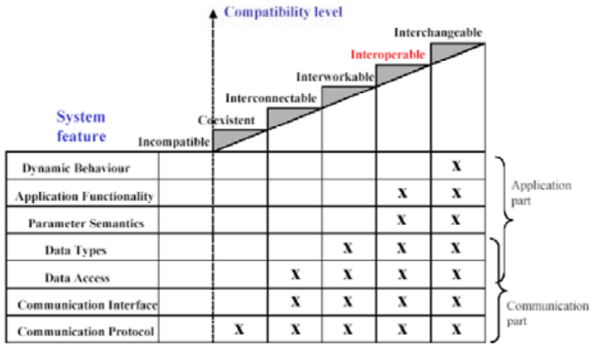

Figure 5: Compatibility levels based on IEC TC 65/290/DC

Especially the term of Interchangeablity is used as intermediate level of communication and expresses an ultimate interoperation. TCP/IP includes mechanisms that address automatically; the most important implementations are SLP, zero config, universal plug and play and UPnP[13]. Combinations of services and processes, as desired in DM, are e.g. supported by service oriented architecture (SOA). Functions are not addressed directly; instead services are requested via defined interfaces[14]. The service program acts as an intermittent between the client and the provider. SOA is therefore an important vehicle for pay services and a significant step towards new concepts of smart DM for addressing services via networks

[13] The procedure for discovery is another important part, though the most common are universal description discovery and integration UDDI and WS discovery protocol, generally based on XML, Web service descriptions annotated in WS DL and messages encapsulated in the Simple Object Access Protocol SOAP.
[14] The following features are important: index, representing a collection of services, able for restoration and finding, client for the take up a service and provider, eventually offering service that has been registered.

according to usage, as e.g. offered by cloud providers. The major achievement of SOA is the principle of encapsulation for implementing functionalities on its generic level supporting fold unfold principles by hiding or forgetting functionalities in certain situations. Encapsulation also supports mappings between functionalities on different levels of detail of the equipment and various stages of granularity.

8. Autonomy

Units demonstrate autonomy or are called autonomous, if these units are able to perform their actions without the intervention of other entities (Hasselbring, 2000). Autonomy includes the ability to interact or to self-organise in response to external stimuli, establishing a positive self-fed loop with the environment. Innovations and developments have rapidly contributed to higher intelligence of a number of manufacturing units allowing self-organisation, self control and eventually full autonomy of factory objects and units (Cloud). Autonomous units may now do their communication independently and may decide how to handle interactions with the outside world, by use of de-centralised decision making and by the formations of autonomous hub organisations with own rules and procedures within a collaborative process or supply network. For differentiation of actions and decision mechanisms in context aware manufacturing equipment, a differentiation of context dimensions may be introduced (Prekop & Burnett, 2003):

- -External (physical) refers to context that or captured by units' interactions or can be measured by hardware sensors, i.e. location, movement, alignment parameters, strategic input
- -Internal (logical) is unit specific, i.e., goals, tasks, objectives fulfilments, KPIs, improvement effects, operations or processes.

Dependent on captured and monitored data, events or stimuli, a manufacturing object may have to become active. Most important are models for decision procedures, so the manufacturing objects can adequately respond to monitoring results, if actions are required. Models to support units on the decision making also regard possible strategies to activate, guaranteeing adequate alignment and the preconditions and cases in which these strategies could be activated. The objective in the model is to maximise the performance obtained through the strategies activation, considering that an active strategy positively or negatively influences the KPIs defined to measure an objective.

Smart units may have capabilities to take certain actions as simple as switching from state to state or as complex as adapting the behaviour by other decision-making, action plans for self-healing, self organising and self sustaining. Depending of the smartness of the unit, the degree of autonomy may vary.

The starting point for a definition of a unit's autonomy is the ability of units to independently define and negotiate own objectives and pursuing strategies to achieve or to approach objectives. Within DM processes, autonomies are always restricted by the mode how other network units activate their strategies and how they define their objectives. Alignment of strategies and the harmonization of objectives include decisions concerning partners' selection, contract agreements, objectives' re-definition and performances as well. The network units have to keep own objectives and network objectives aligned with other units objectives in the network or check modified structures for collaboration by adapting or renegotiating links, restructuring network solutions and confirm or revise missions. Reciprocally, any misalignments will result in possible conflicts between the implemented strategies and the defined objectives, jeopardizing the benefits of collaboration or even breaking up processes. Misalignments and overstretching of the resource base certainly reduce or eliminate a unit's autonomy.

Standard Objective Bundle, decision space and negotiation of objectives is outlined in Kuehnle, 2013. A respective commercialised method for assisting in designing and identifying the goals has come up as Goal Directed Task Analysis (GDTA) process, Fig. 7. Actionable sub-goals ultimately achieve the original goal. For each sub-goal it must be considered how the operator will attain Level 1 projection, Level 2 comprehension, and ultimately Level 3 perception. Once, the business goals of a unit are clearly understood the configuration can be designed.

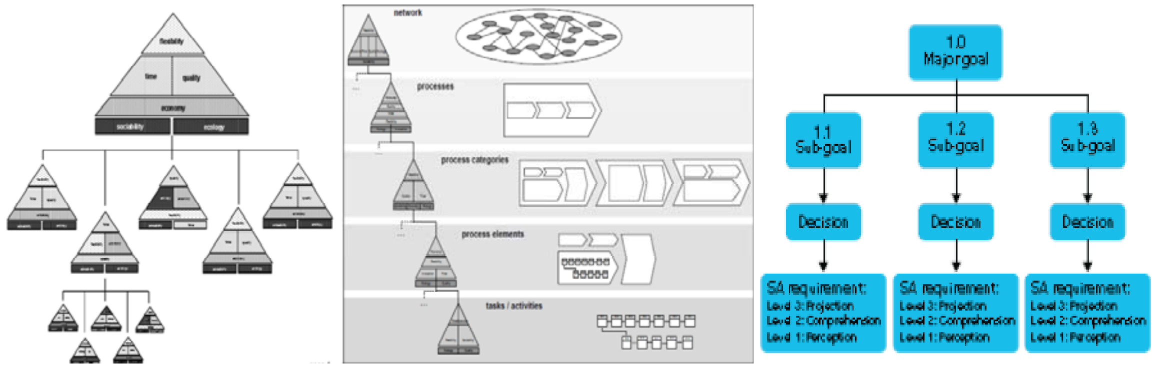

Figure 7: Break - down of network standard objective systems according to self-similarity principles (Kuehnle, 2013), implemented as GTDA software design (Krajewski, 2014)

9. Modularity

Units are considered modular, if they can be decomposed into components that may be interchanged and matched in various configurations. The respective components are able to interact, to connect, to exchange resources, using standardized interfaces. Different from monolithic systems, modular units are loosely coupled. Modularization entails the ability of processes, information systems and products to be packaged as reusable modules that can be (re-) combined with other modules, collectively making up new, value-adding artefacts. Modularity relates to the degree of dependency of elements of the module and is realized by allowing loose coupling between modules, implying that modules should have as little interdependencies as possible. In this manner, modular designed objects behave like autonomous network constituents, which can be networked in a relatively straightforward way. Standardization is the coordination mechanism of preference allowing modular networked objects to be synthesized in a standard manner, decreasing the need for mutual agreements on interoperability. As modularity in manufacturing is not a new concept, there are already examples of modules in DM systems, especially in the areas of control systems, equipment design, and human resource development and in enterprise management[15].
The intrinsically heterogeneous nature of modular systems enables to cope with various technologies and tools. In manufacturing successful use of modularity is mostly based on the ability to align process steps involving different units in order to form viable and efficient value chains by transmitting and exchanging data in a seamless way. Abilities to combine modules, abilities to understand systems of systems and its components and variably combining these, are crucial.
Naturally associated with modularity is the property of compositionality, which means that higher level systems' properties can be derived from the local properties of individual components. Compositionality is frequently impacted by strong interdependencies of software and systems adequately designed with embedded higher level properties.

[15] Prominent examples are distributed controls for operations engaging one or more components, equipment in flexible equipment for discrete manufacturing, shop floor autonomy and empowerment of self managed teams, fractals as well as modular interpretations of enterprises in the concepts of virtual factory, virtual enterprise or extended enterprises, primarily aiming at increased agility and flexibility.

Major challenges for modularity are especially the alignments of human resource practices and information systems, so fragmented operations can be adequately supported by human capabilities. More intelligent units, e.g. smart objects, will enclose control and decision processing. It is decisive, in which way the units or activities are interconnected. Modularity also implies that, aside local feedback and local decision-making, capabilities are offered for prioritizing task allocation and capabilities are available for the execution of partial process chains.

10. Scalability

The capability to extend/reduce resources in a way, that no major changes in structure or application of technology are necessary, is generally referred to as scalability[16].

Due to stronger links between cyber objects and real manufacturing units, the term of scalability evidently becomes highly relevant for DM and manufacturing networks. Of course, a main concern is the capacities' scalability, i.e. the facility to increase or decrease necessary resources to efficiently accommodate broadly varying capacity loads. For example, cloud manufacturing gives the cloud consumers options to quickly search for, request and fully utilize resources procedures, e.g. search for idle and/or redundant machines and hard tools also in other organizations, in order to scale up manufacturing capacity.

Scalability can be seen as one important requirement to realize self organization in DM as it enables adapting processes rapidly in highly dynamic environments. Moreover, in DM, such adaptation processes are gaining importance in plug & work applications. Scalability may refer to the commodity background as discussed in the remote manufacturing cloud, e.g. more machines of the same type in different sites or different companies to fulfil large order quantities in shorter time.

Another field of scalability discussions is the area of control and computing power in the area of cloud computing.

11. Conclusions and Outlook

Additional machine capabilities will completely and rapidly change manufacturing all over the globe. Wireless communication, powerful online identification and localization devices have been successfully integrated in manufacturing already; now novel upgrading functionalities are introduced to the shopfloor. There is certainly much more to come, especially if we imagine implanted or embedded processors in practically any object and any piece of equipment. Mechanisms can be implemented for virtually composing products or for intelligent components finding each other on the path to value creation. Powerful and efficient applications, available as cyber physical systems, as Internet of things, pervasive computing or machine to machine communication will make Distributed Manufacturing a preferred model to produce.

Wireless technologies will further strengthen telecommunications' involvement in manufacturing. This tendency has just started to gain ground by the introduction of efficient tracking systems in synthesis with cloud computing solutions. Manufacturers of computer hardware as well as software vendors will have to take into account this virtualisation of resources. After some reluctance of leading software providers to offer these upcoming services e.g. cloud, impressing solutions have quickly changed attitudes. Software as a service, infrastructure as a service etc. are fully integrated in important software service programs. Anything as a Service (AaaS) could be the wording anticipating more upcoming options.

Additional equipment features, such as awareness, autonomy, modularity, scalability and networkability will step into the manufacturing thinking, which might be called smart

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[16] It is measured in dimensions such as administrative scalability, functional scalability and capacities' scalability. Scalability in Manufacturing refers to the ability of a manufacturing system to handle growing or shrinking amounts of loads or usage in a smooth manner by its ability to be enlarged or reduced to fully accommodate the growth or the shrinks.

distributed manufacturing. Management should be aware of upgraded machines and manufacturing equipment, orders and products, parts and pieces.
Networkability will gain utmost importance on all levels, be it for all KPI's on all levels, additionally introduced network ability parameters or network rules. Management could get prepared for situations where network ability and alignment parameters have higher priority in comparison to traditional KPIs.

Observing the players from telecommunication, hardware makers, software designers and systems integraters and the innovation power behind, it is obvious that there will be more intriguing innovations ahead. All controls of machines, robots and other equipment may be upgraded to emulate all capabilities and functions in order to ensure IP interoperability. Multi-agent systems navigate units by polling and negotiating functionalities to build up optimum process sequences. Both, product design and equipment design will have to be revised completely. Increasing portions of manufacturing will become information, further optimising resources' consumption and instigating the reuse of material as well as the after-use of products. Companies should prioritize to upgrade their equipment and to take "smart" investment decisions on new machines. The melting of key information technologies is only at the beginning of an era; the first humanoid robot, able to replace humans on the shop floor, is expected to appear latest by 2025.

Management should be aware of alternative network configurations at any time and have evaluations ready. Time and history will, in most cases, inhibit to switch to the optimum network configurations. It will only be possible with some delay. Nevertheless all alternatives should be prepared as plans, ready to be activated, as soon as the implementation situations occur. Companies should continuously question their strategies. Business models are jeopardised and constantly flowing, key competencies keep repositioning. Pressure will come from companies, taking higher risks in outsourcing ICT, as the advantages are amazing. Inside and outside of companies, there will be three top priorities for information, data, and procedures: 1. security, 2. security, 3. security!!
Important studies from renowned institutions indicate rationalisation effects that could cut the workforce in industry down to 50% within the next 10 years. The remaining half will have skills that differ from today's qualification schemes (Davis & Edgar, 2011). The shopfloor will be the domain for digital experts, placing emphasis on developing IT skills and new-media literacy. Man machine interfaces and employee involvement have always been hot research spots and will continue to provide a plethora of problems for intensive actions. However, progresses in body area networks will simplify many discussions. The tendency shows a clear development towards a strong involvement of digital natives on all levels and in all sectors of industry.

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Service innovation in China: Development and implementation of a logistics platform solution

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ABSTRACT

Purpose – The aim of this paper is to advance our understanding of service innovation in China and to identify the major drivers and impediments for manufacturing companies pushing into services in China.

Design/methodology/approach – By employing an in-depth longitudinal case of a Chinese company, the paper investigates how a traditional manufacturing company developed and implemented a 'road-port' logistics concept in the local context. We draw on the resource-based and institution-based view as well as theories of innovation.

Findings – The 'road-port' platform concept has a potential to transform the industry by increasing transparency and connectedness between track owners and third-party logistics (3PL) companies. We find that the service concept helped the company to diversify as well as enhanced its growth and competitive advantages in a very competitive environment of the second and third tier Chinese cities. Both internal and external factors played a significant role in influencing the development and implementation of service innovation in the case. The paper details and discusses the factors that affect service innovation in China.

Research Limitations – The study is exposed to the limitations associated with the use of qualitative methodology based on a single case and geographic delimitation. Rather than providing definite answers, the findings of this study should be seen as propositions which open avenues for future research on the subject.

Implications – The findings may be useful in informing our expectations about the push of many Chinese manufacturing companies into services. The paper provides insights into the development and diffusion of service innovation in many fast transforming industrial companies in China. Lessons for other developing countries can also be drawn from the study.

Originality/value – The paper addresses the topic of service innovation in China, which has so far received a limited attention in the management literature. By presenting an in-depth case study, the paper highlights main factors and dilemmas underpinning how Chinese companies are seeking to create a foundation for growth and development based on innovation.

Key words: Service innovation, logistics services, China, case study

INTRODUCTION

In the past two decades, China has earned the reputation of a manufacturing power house of the world. Chinese companies in their vast numbers have been very successful in exploiting their access to low-cost labour and have established themselves as unbeatable high volume low-cost manufacturing champions. However, recently growing number of Chinese manufacturing companies are seeking to recalibrate their focus from routine transactional tasks to more knowledge-intensive and innovative ones and by doing so to create a foundation for growth and development based on innovation.

This trend seems to be congruent with the recommendations of numerous studies analysing how China can maintain its rapid growth, while realizing the potential to become a modern and creative high-income society (e.g. Sheng and Wong, 2011; World Bank, 2013). World Bank (2013) analysis emphasizes competitive pressures for Chinese companies to engage in product and process innovation. An ample array of successful Chinese innovative firms demonstrates that China is already far ahead of most other developing countries and its firms are rapidly building the credible foundations for innovation. However, many challenges remain. Many Chinese manufacturing companies are rapidly approaching their technology frontiers and are in need of new sources of competitive advantage.

Large potential for this may be found in China's relatively underdeveloped services sector. Compared with China's manufacturing sector, the development of services has been lagging behind for the past several decades of the economic growth. However, according to the World Bank (2013) the situation is likely to change with the Chinese economy transforming itself towards becoming more complex, knowledge driven and services oriented. On the one hand, such a trend creates new opportunities for manufacturing companies willing and prepared to step into largely unknown for them territory of services. On the other hand, it is also associated with significant challenges. At the company level, the implications may be very widespread and involve value proposition and value delivery changes. However, implications may also be felt at the industry level where a new service offering may disrupt or even redefine the entire industry.

Therefore it is important to advance our understanding of these implications and to unravel what drives the service innovation and what are the impediments of this process. According to Dodgson & Xue (2009), the development and implementation of service innovation in Chinese companies is an imperative which has not been adequately addressed in the literature which predominantly focused on innovation in manufacturing rather than services. This paper seeks to contribute to bridging this gap and answer: *what does service innovation entail at the company level and what are major drivers and impediments of service innovation development and implementation in Chinese companies?*

The paper does it by investigating a case of a Chinese industrial company, which for the past ten years has been actively working on developing and implementing a logistics platform solution. The paper has four parts. The following section introduces the theoretical background of the study. We then proceed with describing the methodological approach and the case study. The third section presents the discussion and analysis of the case. The paper closes with conclusions and suggestions for how to unravel the tentative results further.

1. THEORETICAL BACKGROUND

1.1. Service innovation

The importance of services is growing all over the world. The contribution of the service sector to the GDP is on the rise both in western and emerging economies. Moreover, services are characterized by a very high level of dynamism and potential for innovations (Berry et al., 2006). Therefore, it is not surprising that academic interest in services and service operations management has also grown (Johnston, 1999). Studies on innovations in the service sector have also gradually evolved. However, compared to similar investigations in the manufacturing sector, research identifying innovation types, investigating management practices and discussing innovation performance in services has been lagging behind similar investigations in the manufacturing sector (Oke, 2007).

According to Gallouj and Weinstein (1997) the analysis of innovation in services is a challenging task for two reasons. First, innovation theory origins are to be sought in the manufacturing sector and technological innovation. Second, the properties of services make the use of the traditional output criteria (e.g. productivity) difficult. The existing scholarship on innovation in services reflects these challenges. Some studies focus on the introduction of new technology in services; this in many instances leads to process innovation and the view is adopted that does not see services in isolation from the technological advancements. Conversely, the other stream adopts the view that innovation in services can exist without technological innovation.

Some studies focused on differences between new product development and new service development. The characteristics of services, such as intangibility, perishability, heterogeneity and simultaneity, point to differences between services and tangible product (Segal-Horn, 2003). In spite of these differences, Oke (2007) finds that the terms ‘service product innovation’ and ‘product innovation’ have often been used interchangeably in the literature to describe changes in the core offerings of companies to create new revenue streams. In the case of services, however, these changes tend to involve much closer than in the manufacturing environment interaction with customers who are an integral part of the service delivery process. To accommodate for this, Ramdas et al. (2012) emphasize four dimensions that need to be considered in service innovation: 1) the structure of the interaction with the customer, 2) the service boundary, 3) the allocation of service tasks and 4) the delivery location. Furthermore, service innovations may be related to variations in core service product and/or add-on service processes enhancing the service experience for the customer (Oke, 2007). Following the established stream of literature on manufactured product innovation, service innovation literature also distinguishes between service innovation projects with different degrees of innovativeness ranging from incremental to radical (Cooper at al. 1999) and point to their positive relationship with firm performance.

Traditional industrial firms are also increasingly looking into the potential of services. Drawing on a broad array of examples, Pawar et al. (2009) find that actual manufacturing operations now account for a smaller share of profits in many traditional manufacturing firms. The provision of services is increasingly taking over fabrication processes. In discussing the origins and rationale for this, the literature commonly puts forward three sets of drivers: financial/economic (services provide new stable source of revenues), competitive advantage (services are more difficult to imitate, thus providing a strategic source of competitive advantage), and marketing/demand (customers are demanding more services) (e.g. Baines et al., 2009; Gebauer & Friedli, 2005; Oliva & Kallenberg, 2003; Schmenner, 2009).

For a long time services have been considered to be an area where western companies have an inherent advantage. However, the situation is changing fast with many companies from emerging markets pushing into services. One of the targeted contributions of this paper is an investigation of service innovation in an industrial company in China.

1.2. Innovation in China

The role of innovation in creating a foundation for growth and development is difficult to dispute. As a result of that, growing numbers of Chinese companies seek repositioning from low-cost high volume manufacturing to more knowledge-intensive and innovation-based activities. Many Chinese companies aspire to potentially challenge Western hegemony in innovation. This aspiration is supported by China's policy making mechanisms that promote the upgrading of the country's economic structure through focus on indigenous innovation and, as Haour and Jolly (2014) put it, making China the next innovation hot spot for the world. There are many connotations prescribed to the concept of indigenous innovation by academia and practitioners. In this paper, we adopt the definition used by the Chinese government, which defines indigenous innovation in terms of innovation developed at home, i.e. 'Chinese technology for Chinese problems'.

According to Johnson and Chuang (2010), indigenous innovation takes place within the national system of a particular country and comes from within the system rather than is transferred from elsewhere. Although acquisition of technology from abroad is an important source of innovation (Pech et al., 2005), the development of superior technologies and innovative concepts at home plays a much more important role for competitiveness of the economy and its firms (e.g. Lazonick, 2004; Dodgson & Xue, 2009).

Numerous studies show that the task of enacting home-grown innovation is not easy. Many Chinese companies face shortages of innovation management skills and experience difficulties with financing breakthrough innovations which do not guarantee immediate returns (Dodgson & Xue, 2009). Several studies (e.g. Zhang, 2011; Zhu et al., 2012) outline and discuss other institutional challenges to successful innovation that Chinese companies face both domestically and internationally, including competition fairness, access to financing, regulatory and tax burdens, lacking support systems. Although a significant progress have been made, China and its companies still face serious obstacles in achieving growth based on innovation. Johnson and Chuang (2010) argue that while the numbers for China's growth in education and areas of science and technology are staggering, there is some evidence that the quality of the output needs further improvement.

According to Dodgson & Xue (2009), one of the major challenges for innovation in China lies in the difficulty of transitioning from the business model based on imitation to one that is underpinned by true innovation driven by R&D and new product development. Tzeng et al. (2011) analyzed the roles played by the state, the social environment and the market in overcoming this difficulty and developing indigenous innovation and entrepreneurship. Their findings suggest that the three institutions play different roles in nourishing indigenous firms at the various stages of development. At the start-up stage, the state creates appropriate contexts that stimulate entrepreneurial motivation. At the growth stage, the social environment plays a more important role. At the mature stage, the market role is emphasized in enhancing or destroying the innovative capabilities of domestic firms.

In their analysis of barriers to innovation in China, Zhu et al. (2012) propose a cost-risk-opportunity innovation triangle model. The three dimensions of the model (opportunity of innovation, cost of innovation and risk of innovation) categorize innovation barriers faced by companies embedded in the Chinese context (Figure 1).

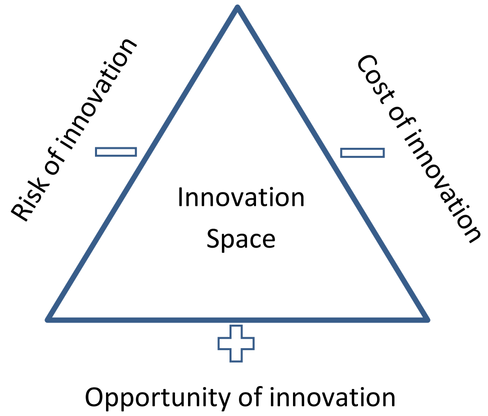

Figure 1. The space of innovation

In terms of the effects of the three dimensions, when opportunity of innovation increases, it positively affects the space of innovation; while the increase in cost and risk of innovation has adverse effect for the innovation space. We will return to the dimensions of this model in the analysis of the drivers and impediments of service innovation in the case.

Some recent literature also focuses on the underlying firm level mechanisms through which innovation can be achieved. For example, Li et al. (2010) examine how behaviour control and output control can influence acquisitive learning and experimental learning in order to produce positive impacts on innovation. Lin (2007) found that such internal factors as organizational encouragement and quality of human resources have significant positive effect on innovation in Chinese logistics service companies. However, the studies at the company level are rare compared to those which examine where China stands in terms of country-level indicators of innovation based on the analyses of educational, science and technology, and economic systems (e.g. Sheng and Wong, 2011; Wang & Hong, 2012). Therefore, this paper attempts to cover not only external factors, but also look at internal factors, resources and features of organizations which influence the development and implementation of service innovation initiatives at the company level. We pursue this objective by conducting a longitudinal case study of a Chinese industrial firm expanding into the logistics sector.

1.3. Logistics services in China

There is a great untapped potential in the services sector in China. As it was mentioned above, general literature on innovation is biased towards innovation in manufacturing, and so is the literature on innovation in China. With very few exceptions (e.g. Lin, 2007; Chen et al., 2011) it has been predominantly focused on manufacturing rather than services and often ignored unique characteristics of services which have to be taken into account when studying service innovation. In this paper we chose to narrow our focus on one logistics services, one of the strategic service sectors of the Chinese economy.

Since China has become the world's largest manufacturing base, the demand for logistics services in the country has been growing fast and the logistics sector has become one of the key sectors of the economy. Efficiently organized logistics function holds the key to potential optimization in the supply chain, which is an important item on the agenda of many Chinese companies looking for new sources of competitive advantage.

As far as the road transportation is concerned, it plays a crucial role in the Chinese logistics sector and covers approximately 70% of the total transportation in China. The gross road freight companies' turnover reached nearly RMB 2 trillion in 2012. However, according to Lin (2007), the efficiency of the road transportation in China can be improved. More service innovation is needed in the road transportation in order to achieve this and reduce the transportation cost in China. Among significant barriers for further development of the sector in China, Lin (2007) highlights the lack of cargo tracing services, the lack of delivery reliability for local carriers, the lack of carrier selection, complicated customs procedures, and fragmentation of transportation networks.

Although there are significant barriers and the logistics sector in China still lacks efficiency and lags significantly behind the major industrial nations, the World Bank's Logistics Performance Index shows that China, rank 26, leads among the developing countries (World Bank, 2013). In August 2011, the Chinese State Council issued new directives aimed at the sustainable development of the country's logistics sector. Therefore there is a big market opportunity in the logistics sector and potential to become a very fertile ground for new breakthrough innovations redefining the sector for years to come.

The so called logistics sector consists of a very broad array of actors ensuring the flow of raw materials, semi-finished and finished goods, as well as related information between the points of production and consumption. In addition to more traditional transportation and warehousing services, logistics providers are increasingly looking at innovating other higher-value added services, such as data and materials management services (Berglund et al., 1999).

Lin (2007) classifies innovation in logistics technologies into four groups: data acquisition technologies, information technologies, warehousing technologies, and transportation technologies. All four areas offer a great potential for innovation in China's logistics sector. Most operations in China's service sectors are labour-intensive and rely on the input of a large number of service workers. One potential area for increasing efficiency lies in the transformation from labour-intensiveness to knowledge-intensiveness. Lin (2007) argues that China's logistics service providers have to adopt technological innovation to improve their process efficiency and provide better services. Some analysts suggest that the sector should subscribe to the latest e-commerce trends and invest extensively in information and communication technologies which could drive and re-shape the market demand of logistics services and push the development of the sector. Others point to the potential of outsourcing logistics services to the third party logistics providers as a way to increase the overall efficiency of the sector. In the remaining part of the paper we turn to our empirical efforts, where we present and discuss a case of a Chinese industrial company which for the past ten years has been looking for 'win-win' solutions for the most pending problems of this strategically important sector in China.

METHODOLOGY AND CASE STUDY

1.4. Methodological approach

Our approach to answering the research question of this study is based on the principles of engagement with practice through case studies (Voss, 2009; Yin, 2009). The case study strategy of inquiry was chosen for the study for several reasons. First, case studies enlighten and explain real-life phenomena that are too complex for tightly structured designs or pre-specified data sets (Voss, 2009; Yin, 2009). Second, the case study strategy is suitable for unravelling concepts which have not been deeply investigated so far (Eisenhardt 1989; Yin, 2009). Third, the choice of the case study strategy is based on the fit between case research and operations strategy (Voss, 2009), which is acknowledged but underexplored in the literature.

Therefore, the empirical foundation for this paper consists of a case study of a Chinese company behind an innovative logistics concept developed in-house at its home base. The company was intensely followed by two of the authors independently in the period of spring 2012 to summer 2014. The case description presented below is based on three site visits in China, semi-structured interviews and informal meetings with company representatives, including the head and deputy head of the logistics division, members of the strategic management team for the logistics division. In addition, secondary data and company materials were used. These included: annual reports, press releases, presentation material to customers and stakeholders, media material, and other secondary literature sources. Furthermore, follow up e-mail correspondence and data validation by the company were conducted in order to increase validity and reliability of the study.

The key criteria for the selection of the case were: 1) country of origin - China; 2) development and early stages of implementation of a strategically important innovation product or solution in the logistics industry. Through these screening criteria and on the basis of considerations about the access to potential data (including commitment of interviewees, availability of documents, etc.) the case study presented below was selected for this investigation.

1.5. Case Company Alpha

Alpha's Profile and History

The original name of Alpha Group translated into English can metaphorically be understood as 'Going far'. The company started as a family business in 1986 with just 2,000 RMB. The core product, the company began with, was the washing liquid produced using very basic mixing and compounding techniques. In the late 1980s, the market in China was not saturated and competition in the sector was relatively small. Since then, Alpha Group underwent tremendous growth and today it is a renowned cross-sector, non-state-owned, high-tech enterprise group in China. It is involved in manufacture (chemicals), logistics, agriculture and financial services.

The revenue of Alpha Group in 2012 reached 24.9 billion RMB. There are more than 7,500 employees in Alpha Group. The Alpha Group was ranked in China's top 500 non-state-owned enterprises and in China's top 500 brands.

Alpha Group is still very focused on the chemical sector where it began. Before 2000, Alpha Chemicals was the only sector the company was operating in. In 2014, the chemical arm still remained a profit center of the company, but the three other SBUs were gaining fast. Alpha Chemicals is listed on the Shenzhen and Shanghai stock exchanges. Alpha Agriculture is one of the largest Chinese providers of commercial seedlings and top-grade flowers. With the development mode of "company + nursery ground + farmer", in 2010, the agriculture park operated by the Alpha Agriculture had become a national agriculture science park.

In the logistics area, Alpha separated the transportation department providing the logistics service for the own products of Alpha to be a sub transportation company, called the Alpha Logistics in 1997. Since 1998, the Alpha Logistics had provided the third party logistics (3PL) service. A big turnaround in the logistics unit of the company came in 2002, when the company decided to establish a ''Road-port' logistics' system, which according to the company and some of its 3PL partners became one of the most valuable innovation in China's logistics sector and contributed to improving the low efficiency of road logistics. Currently, the Alpha Logistics is gradually building up its national logistics service platform and grows rapidly.

'Road-port' Solution for China

'Road-port' as any other port, i.e. seaport or airport, is a platform on which Alpha Logistics brought together different actors: goods owners, 3PLs, individual vehicles owners, government agencies dealing with the tax and custom procedures, accommodation services providers, vehicle service companies, etc.

Besides being an interesting concept in general, the road-port solution was special for several reasons. First of all, the idea was developed at home to target a very specific problem of the industry – fragmentation and lack of transparency. Secondly, the platform epitomized the 'win-win' principle, the founder of the Alpha Group strongly believed in. The platform created a space for efficient and effective delivery of various services (e.g. truck servicing, invoicing, IT support, goods information) and resources to the users of the platform, allowing them to get better at what they did. The success of all user groups and society as a whole also meant success for Alpha Logistics resulting in the realization of the win-win principle.

Although there are many different activities, the platform was mainly designed for connecting track owners and 3PLs. It was a big breakthrough in the industry, because as a rule drivers had limited information about where the consignment might be. 3PLs on the other hand, might have had enough consignments, but not enough vehicles or drivers who could provide price competitive services. Therefore, Alpha Logistics provided a very valuable service to the market – service of visibility, transparency, connection, and trustworthy environment. A smart phone application available for the users of the platform helped to coordinate and access information about supply and demand. The application was also designed for O2O, i.e. integration of on-line and off-line services of the platform, and better monitoring of the goods flow. As one of the interviewed goods owners stated: ‘We face a challenge of tracking where our goods are and who takes care of them. The platform solution is a helpful way to overcome this’. Moreover, the platform also performed some functions on behalf of local authorities (including administration of official freight and tax forms). On average, ‘smart’, i.e. information and data backed, way of connecting 3PLs, truck and goods owners helped to reduce the transaction waiting time for consignment from 48 hours to 6 hours, reduce the number less than full load and free load freights.

In order to attract more truck owners and logistics service companies to join the ‘Road-port’, besides the transportation information, Alpha Logistics was constantly working on developing new services for the platform users, such as establishing Road-Port Expresses, accommodation solutions for drivers, truck fuelling services. After 10 years development, the ‘Road-port’ of Alpha Logistics could boast an impressive track record. It attracted almost 3000 3PLs, especially small-and-medium size enterprises (SMEs), more than one million truck owners to share the logistics information with more than 100.000 good owner companies.

The origins of the concept can be traced back to Alpha’s truck team for its chemical business. In the period of 1997-2000, the fleet of approximately 300 company trucks was established. However, the company was growing fast and this size soon was limiting for further development of the company. In the late 1990s, some managers from the logistics team started questioning the principles of very harsh competition instead of collaboration. From here emerged an idea of concentrating on some other business models where the company could be successful and profitable by establishing collaborative platforms benefiting Alpha and society as whole. The idea was very much supported and driven by the founder of the company.

The resource accumulation was quite rapidly completed and three first individual platforms rolled out. In general, one platform requires approximately 500 million RMB investments. The amount is quite large for a privately owned company. In spite of this, within three years after the first platform in Hangzhou, Alpha Logistics builds another two platforms in Suzhou and Chengdu. Next two platforms in Fuyang and Wuxi are under construction. The business for them is growing very fast with an annual increase in revenue of approximately 100%. Alpha Logistics is going to establish a national logistics network consisting of 14-15 by 2017 and expanding further to 40-50 within the next 10 years.

The Road-port solution brought good social and economic profits to Alpha Logistics. For example, since 2009 the platform in Chengdu attracted more than 2,000 3PLs covering 95% of all logistics demand in Chengdu and 85% of all south-west demand. More than 500,000 truck owners (80% of total trucks capacity in Chengdu) and 50,000 goods owners registered for the use of the platform services. Total revenue of transactions of this one platform for four years of operation reached 16,23 bn RMB and 0,65 bn tax paid to the local government. The successful development continued in 2014 with the generated revenue of transactions reaching 1,55 bn RMB for the first half of the year and 51 ml RMB tax payment. Furthermore, logistics outsourcing rate in Chengdu and neighbouring areas increased from 12,3 to 40%. It was estimated that logistics cost of all the parties involved were reduced by 25% equivalent to 1,5 bn RMB, pointing to the direct macro-economic impact and increased cost competitiveness of Chinese firms using the platform. According the Alpha's analysts, the platform in Chengdu also helped to create approximately 10,000 new jobs, register 700 new start-ups in the logistics industry and became a tool for the local government to attract FDIs.

The impact of the concept for the Alpha Group internal operations was also significant. Although, this service innovation was developed and implemented by a separate business unit of Alpha it had implications for the other business units of this industrial group. First of all, a new revenue stream was created and Alpha expected 600 ml RMB profit from its logistics unit in 2014. Second, the transformation of the logistics function had implications for the manufacturing arm of the company. By having an internal fleet of owned trucks, the company often faced bottlenecks related to limited capacity of their logistics function. After implementing the platform solution in Hangzhou, the company got access to more than 100.000 trucks on a continuous basis, which improved its delivery flexibility and dependability.

After 10 years of successful development of the concept, Alpha created a track record, which the company hoped to use for further expansion and creation of a national network of ‘road-ports’. In 2014, Alpha remained the only company in China that operated more than one platform and was on the way of expanding further. Among the factors that could affect the future development of this initiative, the company emphasized the role of government in helping to create rules and standards accounting for the benefits the ‘road-port’ solution could bring to the industry. The planned expansion of the network is capital intensive, therefore IPO options were considered to tackle the challenge of finding the necessary funding. Internally in the company, the ‘road-port’ logistics concept continued to have a great support backed by the hiring of 50 new employees for its logistics unit in 2014. Development and integration of the young talents the company saw as one of the most immediate tasks for achieving its ambitious expansion goals and broadening its platform service portfolio to the new areas such as packaging and green logistics solutions

DISCUSSION AND ANALYSIS

The case presented above demonstrates that numerous perspectives matter for advancing our understanding of service innovation in the specific context of the road logistics industry in China. However, a more important question is how they matter. In this respect the study may offer some insights into how to improve the environment and eliminate the barriers for service innovation in Chines industrial companies.

The business environment in China has come a long way to become stimulating for private companies innovation. In general, the nature of innovation is associated with risk and unpredictability. The case shows that for industrial companies pushing into services, service innovation is even more challenging and therefore requires more nurturing and support. However, if successful breakthrough is achieved, the impact crosses the boundaries of one sector of the economy and is felt not only on the industry or company level, but also on the national level. Figure 2 illustrates the impact of the developed and implemented logistics concept observed in the Alpha logistics case.

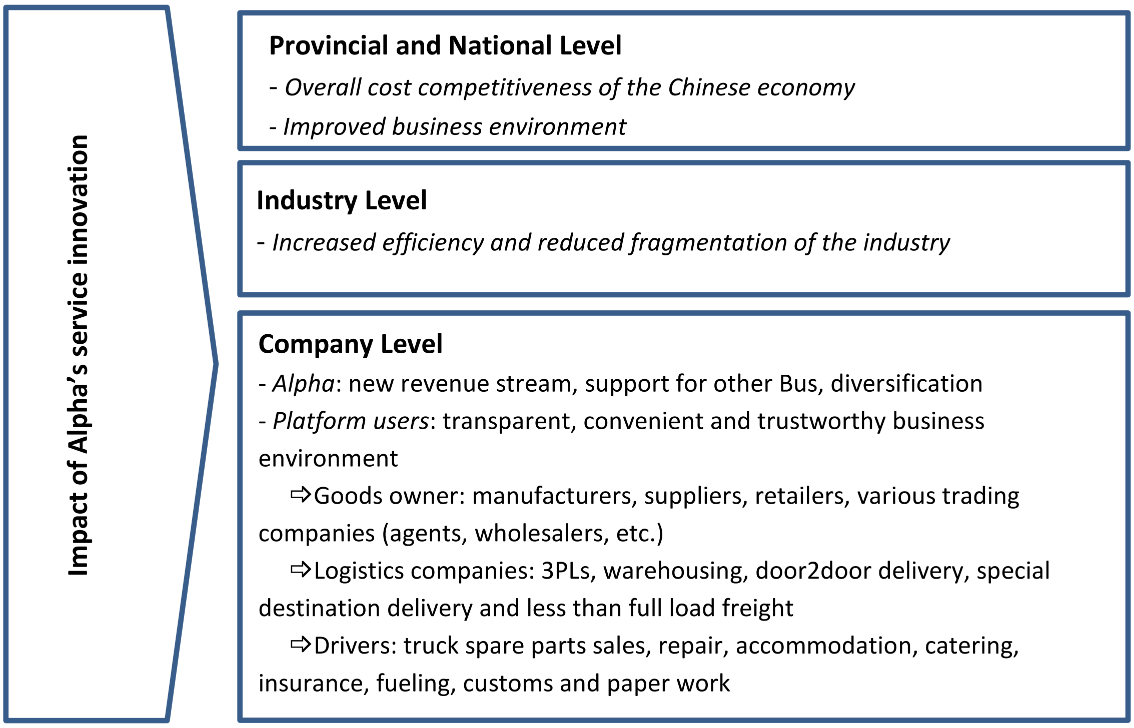

Figure 2. The impact of service innovation in Alpha Logistics

The study showed that the logistics business in China differs substantially from the same kind of business in other countries. According to Alpha, this sector in China is 40 years behind Europe and North America. The best evidence of this can be seen on the streets of Chinese towns. The condition of commercial fleet is rather bad. This example is representative of the state of the logistic business standards for facilities and equipment. The field work we conducted as part of the case investigation confirmed the existence of challenges highlighted by Lin (2007), i.e. lack of transparency, lack of reliability, lack of convenient solutions for carriers' selection, and fragmentation of the industry as whole.

Part of the successful development of the service innovation in Alpha was that as a manufacturing company, it was very much familiar with these problems and was very well positioned to come up with an appropriate solution for them. Referring to the drivers that motivate industrial companies to differentiate into services (e.g. Baines et al., 2009; Oliva & Kallenberg, 2003; Schmenner, 2009), it seems that the demand driver played significant role in the case. However, according to the company the financial (services provide new stable source of revenues) and competitive advantage (services are more difficult to imitate, thus providing a strategic source of competitive advantage) drivers also affected their decision to develop their logistics unit and focus on related services.

The market demand, financial and competitive advantage drivers triggered Alpha to start transforming its logistics division and creating a platform solution that could help to address some of the existing challenges for the actors in the industry. Such a platform was a very effective and cost efficient way to do so. For example, if one party provided consignment information to one specific driver, outside the platform the driver had to pay approximately 200-500 RMB. The price within Alpha's platform was just 10 RMB making it quite an attractive proposition to join. The platform also provided volumes and the critical mass required for a viable business for some 3PLs.

Solutions of similar nature also exist in Europe. For example, the UK-based Pall-Ex Group of Companies is ranked amongst the UK's leading logistics providers. Founded in 1996, the company works with a network of member hauliers to cover every postcode in the UK. Pall-Ex now has access to over 7,500 trucks, 450,000 m2 of warehousing and has over 100 depot locations throughout the UK and Europe. With a rapidly expanding client portfolio that includes many high street retailers and household names, Pall-Ex provides full package of service logistics. Operating from a state of the art transhipment hub, the company continues to develop to be the best in the sector, harnessing technology for materials handling, online track and trace and environmental advantage. Pall-Ex is UK-based but it is rapidly expanding into Europe.

So what makes Alpha's road-port solution unique? By and large, it is the characteristics of the Chinese market. Transferring the Alpha solution to Europe or North America one-to-one would have no chance of survival. Transhipment hubs and internet-based information platforms are more widespread in Western countries. However, in China the physical platform is necessary. Credit society relying on internet is not developed in China and many transactions depend on physical infrastructure and facilities – the face-to-face mode is very important and cash-based transactions lead to deals. Therefore the physical platform provides value in this context.

Furthermore, using Oke (2007) categorization of service innovations, by looking at the solution package we can distil that Alpha was focused not only on core service product innovation, but also add-on service processes enhancing the service experience for its target customer groups. Chapman et al. (2002) refers to several types of innovation as crucial imperatives for innovation in logistics: innovation through technology, innovation through knowledge and innovation through networks. It seem seems that Alpha managed to deliver on all three types successfully coming with a transformative impact for its business model.

Within the company, the logistics unit has been getting more important. The chemical business unit, a traditional industry, remains promising, but logistics potential is increasing. The sector as whole has a long way to go in China and this fact provided Alpha with lots of new opportunities and growth potential. Currently Alpha is one of the leading players offering the industry badly needed innovative products and solutions. The goal is to achieve roughly ten times increase in the next ten years. That means that by 2025, Alpha seeks to create 100 billion revenue businesses. Currently, Alpha sees enough potential in the Chinese market and does not actively look outside the domestic base. Nevertheless, there may be a potential for scaling up the initiative to other south-eastern Asia countries facing similar challenges in their logistics industry.

Alpha emphasized their position on the market as 'Platform operator'. As the head of the logistics unit put it: 'We are not a real logistic company'. The platform means that Alpha was not doing logistic business, but rather provided services and support to logistic companies and mainly focused on the interface between the consignment and the drivers. The service innovation in the case helped the company to create this new niche on the market with the big growth potential. However, realizing this potential faces serious challenges. Some of them can be explained by the framework of the innovation space triangle proposed by Zhu et al. (2012) (Figure 1). For developing further the company will have again to consider how to overcome cost and risk of innovation and utilize to the full extent the opportunities the scaling up of the initiative may bring. For example, in the nearest future, Alpha also set out to create the community of logistics. This would enable the company to provide better solutions for drivers and for 3PLs. The drivers could get better conditions for getting loans for the fleet upgrades and buying new trucks, tires and insurance. According to the company, many of their growth ambitions and ideas related to transformation of the industry in China require government attention pointing to the role of the central and local government as an active player, and not as peripheral contextual factor.

However, the success of Alpha, cannot be explained only by their relationship with the government. Embeddedness in the local context and its manufacturing background may help to explain, why Alpha was ahead of its Western competitors and other local logistics and service companies in coming up with the concept. In fact, Alpha did not even position itself against Western logistics giants because the road-port concept allowed it to create its own niche where it felt secure and confident. Alpha's knowledge and expertise about the local market, arguably the most dynamic and complex in the world, ensures this confidence. A good overview and understanding of 100 million players market is an asset in itself and Alpha successfully exploited it in its journey of rapid expansion. The road transportation is crucial for China and Alpha's physical platform solution contributes to solving societal needs by integrating a very fragmented market, providing important services and means for the commercial fleet upgrade. The solution is proving to be a showcase with many provinces and local governments being interested in the concept. Therefore, Alpha's ambition to have 50 operational platforms in the next ten years may be quite achievable.

Rapid growth is crucial for Alpha, because although rather secure at the moment, the niche is also open for competition. One example to mention is Alibababa's Cai Niao announcement of moving into this business in 2014. However, Alpha safeguards itself and relies on several differentiating elements: 1) high amount of capital required—as mentioned above, establishing a physical platform require at least 500 ml RMB investment; 2) relationship with local government; and the most crucial 3) nuanced knowledge of the industry and its demands.

As far as the characteristics of Chinese market are concerned, they can be seen as one of important drivers as well as one of critical impediments of innovation in China. As shown in the Alpha case, on the one hand, the demand of the Chinese market and increasing importance of logistic industry in China trigger Alpha's innovative logistic platform creation in China. However, on the other hand, the characteristics of Chinese market are also associated with significant challenges for further expansion of the platform which will require full mobilization of internal resources and innovative potential of the company.

CONCLUSION

The principal objective of the paper has been to contribute to the debates about what does service innovation entail at the company level and what are major drivers and impediments of service innovation development and implementation in Chinese companies?

By employing a case study, the paper investigates the trajectory that the company undertook in implementing an innovative 'road-port' logistics concept that was developed in the local context for solving a local problem of transparency and connectedness between track owners and 3PLs. The company succeeded in developing service innovation that generated a new niche on the market and reshaped existing ones. Our main findings demonstrate that although the institutional factors played an important role in creating conditions for the initiative, the crucial drivers of it can also be found at the company level. These included: the manufacturing background of the company and a superior knowledge of the customer needs, attention to developing a scalable and viable business model, focus on attracting and retaining new talents, continuous focus on development, founder's fostered culture that is comfortable with new ideas, change, and risk and, last but not least, the authority given to the SBU management team and their ability to translate their knowledge of the local conditions into a unique service solution that showed a shift from an imitative to an innovative mode of business thinking and practice.

On this basis, we argue that although institutional factors play an important role in transforming China into the innovation powerhouse of the Asian context, more attention should be given to the processes at the firm level. The former has been in a spot light for years, but the latter area has often been ignored.

The study also has a number of limitations, which were beyond of the scope of this paper to address. First, rather than providing definite answers, the findings of this exploratory study should be seen as propositions which open avenues for future research on the subject. Second, there are several methodological challenges. The study is exposed to the usual limitations associated with the use of qualitative methodology based on a single case design. As the next step towards unravelling the tentative result of the paper, we consider expanding its empirical base and developing the ideas further through a multiple-case study design.

At this stage, we by no means claim that based on these results we can explain all aspects of service innovation in China. However, we believe that the findings may be useful in informing our expectations about the factors that affect successful service innovation in China.

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Shifting Targets in Manufacturing Control: Development of a Methodology Considering Human Behavior to Avoid the Lead Time Syndrome of Manufacturing Control

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Abstract
While research has developed a wealth of knowledge with regard to approaches in Production Planning and Control, it often overlooks the fundamental issue of human expectations by assuming "perfect rationality and knowledge" of decision makers. Compared to the vast number of studies on the optimization of manufacturing processes, human decisions and the process of decision-making were rarely subject of these studies. In practice, planners often misinterpret system states or KPI's: If, e.g., planned lead times are adjusted in order to improve the logistic performance, the resulting due date reliability might decrease, which is known as the 'Lead Time Syndrome' of manufacturing control (LTS). Preliminary research has shown the topicality of the LTS in today´s manufacturing systems and provided a mathematical and simulation based investigation of underlying coherences. However, LTS research did not focus on planners' decision-making process, which is accompanied by cognitive biases. Thus, the aim of this paper is to determine requirements of a LTS-avoiding methodology that aims to prevent human mistakes by overreaction or misinterpretation and to derive an initial concept of a visualization-tool.

Keywords: Lead Time Syndrome, Cognitive Biases, Production Planning and Control, Decision-making

1. Introduction

In the past decades various models have been developed in Production Planning and Control (PPC) to improve the logistic performance, which is measured by the achievement of short lead times, low WIP levels, high capacity utilization, and high due date reliability, with due date reliability as the most important target from customer's point of view (Nyhuis & Wiendahl 2009). However, these models often overlook the fundamental issue of human expectations by assuming "perfect rationality and knowledge" of decision makers, such as in the macroeconomic theory of rational expectations (Cochrane 2007). Compared to the vast number of studies on the optimization of manufacturing processes, human decisions were rarely subject of these studies (McKay & Buzacott 2000). In practice, planners often misinterpret system states or the logistic performance. Hence, in order to improve the logistic performance, e.g., planners decide to adjust planned lead times. Against expectations, the resulting due date reliability might decrease due to the so called 'Lead Time Syndrome' of manufacturing control (LTS) (Mather & Plossl 1977). This syndrome was firstly described by Mather and Plossl (1977) and is depicted in Figure 1: A common strategy by production planners to increase due date reliability is to release orders earlier or to add safety lead times (Lindau & Lumsden 1995)), because apparently prior planned lead times were set too short to produce in time. This reaction directly increases the process workload. Consequently, the WIP level rises and lead times get longer and more erratic (Knollmann & Windt 2013b). Finally, this circle of mistakes leads to an even lower due date reliability - although the aim was to improve it - thus demanding for further measures to be undertaken. Ultimately, an increased number of urgent orders become rush orders (high prioritized orders), which results in high sequence perturbations – hence causing an increasing lead time standard deviation and wasted production capacity. In theory, this leads to a vicious circle, which continues until the mean lead times reach a very high level (Nyhuis & Wiendahl 2009).

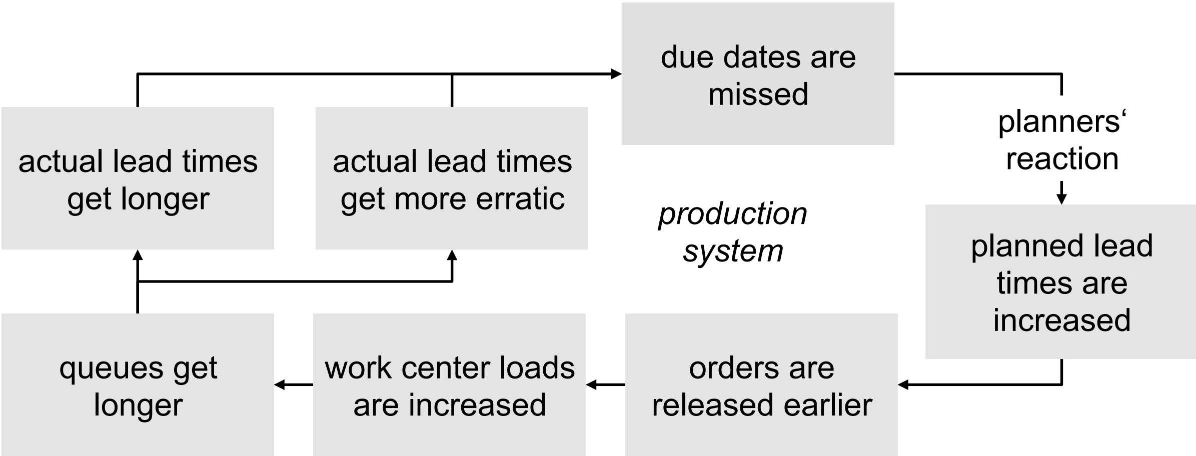

Figure 1. The Lead Time Syndrome of manufacturing control in a production system (based on (Mather & Plossl 1977)

Instead of studying the relationships themselves, several researchers used the LTS logic to introduce production planning and control (PPC) measures that should overcome selected negative LTS interactions or its induction. Examples include assembly controlling (Lödding 2013), workload control (Breithaupt et al. 2002), logistic positioning (Nyhuis & Wiendahl 2006), controlling instead of forecasting lead times (Kingsman et al. 1989), or use of MRP II (manufacturing resource planning) to avoid 'phony backlog' (Wight 1984). By using the clearing function theory, Selcuk et al. initially investigated the influence of the planned lead time update frequency (two-dimensional Markov process) and stated that the LTS triggers uncontrolled production system states with regard to a high mean and standard deviation of lead times (Selçuk et al. 2006; Selçuk et al. 2009). A formal derivation and evaluation of the LTS line of argumentation revealed on one hand that fundamental assumptions of the LTS are still rarely investigated while, on the other hand, dynamic effects and the variable interactions were excluded so far (Knollmann & Windt 2013c; Knollmann & Windt 2013b). Further investigations of system's transient response in scope of the LTS extended the research on the LTS (Windt & Knollmann 2014). Thereby, Windt and Knollmann identified the frequency of planned lead time adjustments and system's delay until adjustments are implemented and take effect as the main influencing variables on the impact of the LTS (Windt & Knollmann 2014). However, extended research on planners' behavior - as the initiator of the LTS - was so far out of scope of the LTS research.

Human behaviors have long been well observed and thoroughly researched in subjects of anthropology, psychology and sociology, where human nature has been in the center of scientific researches (Berelson & Steiner 1964). Nowadays, "humans" are gradually receiving more attention by researchers in other disciplines, for instance by economists. For over three and a half centuries, economic theorization had been depended on the two pervasive axioms of "perfect rationality" and "perfect knowledge" of human beings, rarely studied in conjunction of or with assistance of psychology (Mitchell 1910). In the recent past, economists made considerable progress in this area, which has resulted in the creation of the field of behavioral economics (Tokar 2010). Simon suggests that rationality is bounded by contexts of information, time and cognitive conditions of human beings (Simon 1979).

Several cognitive biases challenge the assumptions in rational-choice model in economics, and reveal that humans systematically go wrong when dealing with complexity and uncertainty (Kahneman 2002). However, questioning planners' reaction has hardly been the focus of research on the LTS.

Moscoso et al. (2011) initially brought together the research on planning instabilities (such as the LTS) and human behavior (such as overreaction). The empirical study introduced the term 'planning bullwhip' that subsumes any kind of planning instabilities that are generated primarily by planning policies and internal actions (Moscoso et al. 2010; Moscoso et al. 2011). According to their definition the LTS is a special case of the planning bullwhip, as it is also a result of planning instabilities. They assumed that in the hierarchical planning structures within a company, dynamics are generated by the discrete decisions that are made at each planning level simultaneously, which deviate from optimal operations and cause instabilities. An essential reason for such deficiencies is because of the overreaction of the planning level decision makers, who constantly change plan parameters to offset deviations on the shop-floor level. In addition, discrepancies between information in reality and data in IT-systems are potential reasons for such overreactions (Moscoso et al. 2011). However, their studies excluded a more detailed investigation of cognitive biases, but rather remain on a meta-level of human reactions under uncertainty. This also counts for the presented holistic framework to address the planning bullwhip. Nevertheless, the research of Moscoso et al. (2011) shows that the investigation of the LTS not only includes a quantification of the chain reaction after planned lead time adjustments, but also the human behavior in complex environments.

The aim of this paper is to develop a methodology to consider human behavior such as mistakes by overreaction or misinterpretation in scope of PPC. This methodology includes the anticipation of the resulting due date reliability after planned lead time adjustments in scope of the LTS and a discussion of requirements for a visualization method of anticipated KPI developments as consequence of possible adjustments. Such a visualization of possible KPI future patterns would help production planners to make the right decisions at the right time. Therefore, initially the motivation for the need of a methodology to avoid the LTS is given by an example case of a production planning system. Afterwards, the research on human behavior in other research disciplines is presented and transferred into the PPC and LTS context. Chapter 4 then outlines requirements for the methodology based on the underlying research questions to deal with the LTS. Finally, a resulting methodology will be presented and discussed to prevent human mistakes of overreaction and misinterpretation.

2. Example case of production planning under uncertainty

The main reason why the chain reaction described by the LTS is able to lead into a vicious cycle is given by the reaction of planners to adjust planned lead times. In practice, planners have to deal with uncertainty about current system states, future demands, disturbances and many more. However, the worst case steady state of the LTS can be observed if production planning and control is performed manually and a lack of transparency about current system states is given. Thus, if planned lead times are repeatedly increased to meet due dates, the cycle of the LTS repeats until lead times reach a high level (Wiendahl 1997; Mather & Plossl 1977). Figure 2 describes the expected steady state if planned lead times remain unused for planning and scheduling. In such situations, orders are planned without calculation of expected lead times and order sequencing in front of the work systems is hardly possible or logical. Due to the immediate order release, high WIP levels and thus long lead times are expected. The lack of sequencing and the long lead times once again lead to a high lead time standard deviation. Finally, the resulting due date reliability is expected to be on a low level.

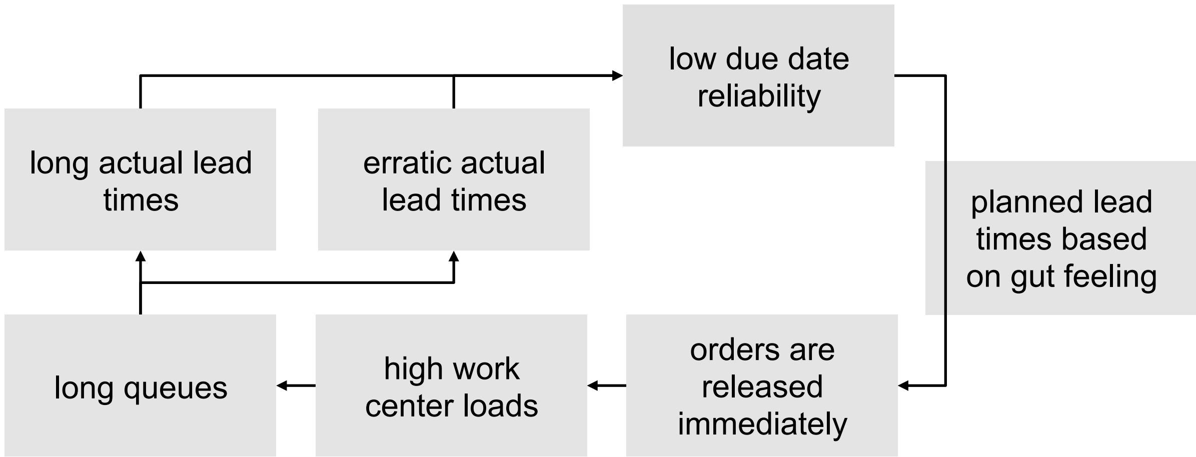

Figure 2. Worst case steady state of the Lead Time Syndrome

The following industry example depicts some of the main observations for such a situation. The case company is a division of a globally operating steel manufacturer. In this job production individual customer orders are processed separately on a given set of machines. The work plans differ between orders because not a single 'product' is produced, but rather incoming materials are characterized. These characteristics are, e.g., surface defects, corrosion behavior or material properties. Therefore, planners have to deal with high uncertainty about future workloads. During the period of investigation no adequate planning system was given, thus transparency regarding system states and logistic target achievements was rarely given. Due to the low transparency and the lack of a PPC system, planners' decisions were mostly based on gut feelings, which induced the situation described below.

At the beginning of the period of investigation, due dates of incoming orders were defined manually by planners. If orders had no predefined due dates, they were scheduled based on gut feelings. Thereby, due dates were set to a date in one, two or three weeks from today on. These due dates defined the planned completion date of the whole order without further due dates of possibly required sub steps. This 'planning' resulted in about 80% of orders with due dates in three weeks, thus planned lead times of 15 shop calendar days (five-day working week). Without adequate planning and controlling, incoming orders were released immediately. More specifically, planned orders were directly given to the first processing step. Without further information about order priorities, workers processed orders in no predefined sequence. It was often observed that either orders were processed that seemed to be urgent or aroused the interest of the worker. Thus, just as rush orders, some orders were finished within a few days regardless their due date priority. Accordingly, other orders were finished too late as they remained in queues even if they were already tardy. If these orders became urgent, they were declared as rush orders, thus leading to even more disruptions.

Exemplary for the low system performance, Figure 3 shows the resulting lateness distribution of the manufacturing process described above. The lateness of an order is defined as the difference between the actual lead time and the planned lead time (Nyhuis et al. 2009). Thus, positive relative lateness implies longer actual lead times than originally planned. The corresponding due date reliability is calculated in Equation 1 as ratio of the number of orders produced with a lateness in between the tolerance period limits to the total number of orders

(Lödding 2013; Yu 2001). Figure 3 shows that only some 18% of all orders are produced on time (given the company specific tolerance period of ±2 SCD). This is due to the high oscillation of lead times and the lack of transparency in planning and controlling. The average lateness is given by -5 SCD with a standard deviation of 10 SCD. Moreover, about 60% of all orders were processed too early, thus blocking capacities for tardy orders.

$$DR = \frac{\text{number of orders with } Low \leq L \leq Up}{\text{total number of orders}} \cdot 100 \qquad (1)$$

DR due date reliability [%] *L* lateness [SCD]
Low/Up lower/upper limit of due date tolerance period [SCD]

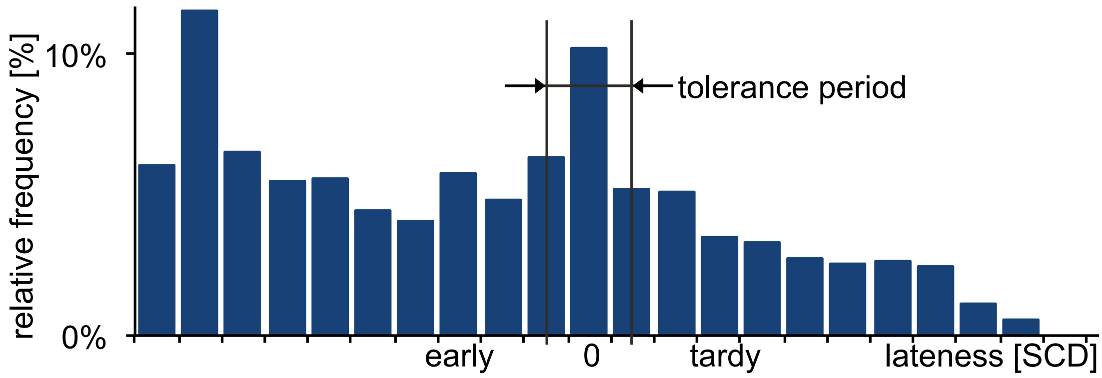

Figure 3. Process lateness distribution for the worst case steady state of the LTS

The presented case shows that the intension of planners to increase due date reliability is likely to lead into a situation of low performance including low due date reliability. Although the described situation depicts the worst case, some general problems of human behavior became apparent in the observed manufacturing system, which are able to lead into the LTS:

- planners adjust planned lead times even if they are aware of the LTS and know that due date reliability might decrease
- a lack of transparency about current system states makes workers prone to high work in process levels to have a 'guarantee' of enough work in the following periods
- without planning and sequencing of orders, workers tend to follow their own sequencing rules (e.g., most interesting or biggest orders first)
- with full transparency about current system states (incl. charts, diagrams and KPI's) planners are often incapable of coping with the amount of information and pick preferred KPI's or diagrams for optimization (e.g., due date reliability)

This non-exclusive list is based on observations made during the consultancy project on which the case study is based. They show that either accidental or intentional misbehavior of workers and planners could lead to a lower logistic target achievement. However, it can be assumed that workers do not intend to decrease the performance, but rather fall victim to the so called cognitive biases. The following chapter gives a brief introduction into the research on human behavior in psychology and matches these cognitive biases to behavior that can be observed in manufacturing companies.

3. Research on human behavior and data misinterpretation

Kahneman presents in his studies a map of bounded rationality that is used in this paper as a framework to introduce possible cognitive biases in the context of PPC (Kahneman 2002). The presented findings include heuristics that are commonly used in the decision-making process which are able to induce systematic errors. Hence, initially a brief introduction into the findings of Kahneman is presented, which are then transferred into the context of PPC.

***The two-system view of cognitive processes**:* Scholars have distinguished between the cognitive processes intuition and reasoning in studies of judgment under uncertainty (Stanovich & West 2000; Kahneman 2002). Stanovich and West categorized the characteristics of these two cognitive processes, which are labeled System I and System II in Table 1. A comparison of the generated effort thereby indicates to which system mental processes should be assigned (Kahneman 2002). Based on this two-system view, Kahneman and Frederick suggested that *impressions* are generated in System I, while all *judgments* are generated in System II (Kahneman & Frederick 2002). They also suggest that the process of monitoring of judgments by System II is quite lax. Thus, intuitive judgments are likely to be expressed, even if they are erroneous. It can be concluded that judgment errors are always errors in System II, which are not unlikely to occur in decision-making (Kahneman 2002). In the context of the LTS planners might intuitive think (without further justification) that a planned lead time adjustment would lead to an increase in due date reliability.

Table 1. Two cognitive systems (based on (Stanovich & West 2000; Kahneman 2002))

System I: **Intuition**	System II: **Reasoning**
Relatively fast	Relatively slow
Parallel	Serial
Automatic	Controlled
Effortless	Effortful
Associative	Rule-governed
Slow-learning	Flexible
Emotional	Neutral

Accessibility of information (Kahneman 2002): While intuitive thoughts come to mind spontaneously, other thoughts might not be accessible for an individual. Thereby, the accessibility of information is defined as the ease with which a mental content can be activated (Higgins 1996). If we relate this to decision making, highly accessible features would be given more weights by decision makers, while features with low accessibility are more likely to be ignored. Unfortunately, there is no evidence showing that the most accessible features are also the most important or relevant ones that are needed for a good decision. However, the accessibility of information can sometimes be increased through experience.

Framing effects (Tversky & Kahneman 1981): A significant aspect of rationality is the invariance of preferences, which means that changing irrelevant features should not change the preferences. The cognitive bias of framing effects violates this aspect. Thereby, outcomes of a certain probability are relatively outweighed by outcomes that are obtained with certainty. This tendency also contributes to risk aversion when people are presented with options involving sure gains or risk seeking with options involving sure losses. Thus, framing effects can be observed in the process of decision-making when alternative descriptions of a problem are highlighting different aspects of the resulting events.

Changes or states (Prospect Theory) (Kahneman 2002): The perceptual systems of a human being have the general property that they are designed to increase accessibility of changes and differences (Palmer 1999). Perception is reference-dependent as "the perceived attributes of a focal stimulus reflect the contrast between that stimulus and a context of prior and concurrent stimuli"(Kahneman 2002). The idea of reference-dependence is conflicting with the assumption in Utility Theory that decisions are independent from the initial state. However, the experiments of Kahneman showed that when subjects are offered two choices between two gambles, decisions are made based on the changes of wealth, losses or gains, not the expected states of wealth after the gamble. Based on this theory (Prospect Theory), one could also expect the evaluation of decision outcomes to be reference-dependent. People take decisions under uncertainty will be largely influenced by their perceptions and evaluations of gains or losses involved in their expected outcomes. Moreover, people's choices cannot be separated from emotion, which is caused by changes. A model utterly dismissing feelings such as pain of losses would simply be unrealistic.

Anchoring and Adjustment Heuristic: When making decisions or judgments in dynamic and complex environments, people tend to anchor on information they know and adjust until a plausible estimate or acceptable value has been reached (Tversky & Kahneman 1974). Sterman (1989) gives an example of anchoring and adjustment by the so-called 'Beer Distribution Game'. The participants have to estimate parameter setting rather than calculate exact solutions due to a lack of time. Results also show that participants underestimated the time delay between initiating and receiving their orders; thus, based on this experience, they modify their desired stocks each time to offset the effects of underestimation beforehand (Sterman 1989). Ultimately, the 'bullwhip effect' is jointly produced by local optimizations and the 'overreaction' of the participants (Moscoso et al. 2011). Surprisingly, participants are unaware that this phenomenon is generated by their own actions ("overreactions"), and attribute the fluctuations to exogenous causes, demonstrated by Sterman as "misperceptions of feedback" (Sterman 1989). Particularly, they fail to account for their individual control actions, which have been initiated but not yet demonstrating the effects (Sterman 1989).

These cognitive biases mapped by Kahneman (2002) have to be considered in PPC, as decision makers often have to deal with uncertainty. Only past data of system states such as WIP levels or capacity utilization levels are exact. Disturbances are mostly unpredictable, such as quality problems, breakdowns, unexpected maintenance, illness etc. (see also (Patig 1999) for an extended list). Also future demands are subject to predictions. Decisions have to be made quickly with limited information, which are often based on intuition and anticipations. More specifically, if planners trust blindly into their intuition, judgment errors are even more likely. To gain knowledge about actual system states, diagrams such as production operating curves (see (Nyhuis & Wiendahl 2009)) or lateness distributions have to be interpreted correctly. Furthermore, not only the knowledge about calculated KPI's has to be given, but also have to be understood and to be seen in relation to each other (e.g., Flow Rate and lead time (Ludwig 1995)). Thus, it is theoretically likely that planners put more weight on favored values when it comes to decision-making, which is often observed in practice. However, consultancy projects and coaching are able to continuously improve the skill to access more process relevant information (Kahneman 2002) (e.g. shown by (Nyhuis & Wiendahl 2009) in a consultancy project). Besides the accessibility problem, it has to be considered that different visualizations or representations of the same information could lead to different decisions. Thus, data have to be prepared and presented in a transparent way. This requirement is also supported by the need to visualize variable developments over time to make changes more transparent. The complexity of production networks makes it impossible for an individual to anticipate effects correctly. The misperception of feedback once again demands for more transparency to avoid sudden overreactions to short term disruptions or fluctuations. Particularly, the anchoring and adjustment problematic describes the situation observed in the LTS. Planners tend to adjust planned lead times instead of entirely reconsidering the magnitude of the value. Moreover, in case of the LTS external influences are held responsible for the in fact delayed due date reliability decrease that seemingly demands for another planned lead time adjustment. The described problems of the cognitive biases of decision makers are now transferred into a methodological framework to deal with the LTS, which is strongly influenced by planners' decisions.

4. Methodological framework of strategies to deal with the LTS

The presented case study and the conclusions drawn from the research on human behavior show that it is yet neither known in practice nor in theory how to effectively deal with the LTS. Basically a strategy to avoid the LTS has to cover the following two questions:

1. If, how and how often should planned lead times be adjusted?
2. Which information do planners need and are there requirements to display them?

A framework to tackle these questions thus could serve as a strategy roadmap to deal with the LTS. The following paragraphs therefore outline the underlying research questions to provide a more detailed list of requirements for such a methodology.

Should planned lead times be adjusted at all?

According to the manufacturing control model of Lödding, lead times and WIP levels can be influenced directly by capacity control or indirectly by planned lead time control (Lödding 2011). Thus, both control strategies are theoretically available to increase the performance of these two logistic targets, which also directly affect the resulting due date reliability. Whether to choose capacity control or planned lead time control was evaluated in a study using a control-theoretic model (Knollmann et al. 2014). It was shown that work output control is only superior for short information delays combined with a high adjustment frequency. With less frequent adjustments or long delays, planned lead time control resulted in significantly higher performance achievements. Thereby, the delay is defined as the time period until adjustments affect the resulting lead times and thus the due date reliability. Depending on the given system states either capacity control or planned lead time control has to be selected to achieve the best performance. Hence, the first requirement of a strategy roadmap contains the option to choose between both control strategies including an instant visualization of the anticipated performance development to enable a comparison.

How and how often should planned lead times be adjusted?

The studies of Selcuk et al. revealed the strong influence of the planning frequency on the impact of the LTS, thus how often planned lead times are updated (Selçuk et al. 2009). They assumed that a lower frequency would decrease the lead time variability. However, it was not possible to define the optimal adjustment frequency that would lead to the maximum performance while avoiding the LTS. Including the delay component into the LTS research revealed that the optimal adjustment period length has to be longer than the delay to avoid the LTS (Windt & Knollmann 2014). It was moreover shown that a reduced magnitude of response leads to a damped LTS impact if planners adjust planned lead times too often in relation to the given delay. Thereby, the magnitude of response is given by the multiplier of the mathematically 'optimal' planned lead time adjustment, which is defined as the gap between actual and planned lead times. Hence, the second requirement of a strategy roadmap contains the determination of the optimal adjustment frequency in dependency of the given environmental situation and includes a consideration of a situation in which the update frequency is possibly too high.

Which information do planners need and what are requirements to display them?

The previous chapter showed that the rationality of decision makers is bounded. The misinterpretation of given information could lead to overreactions such as outlined by the LTS. To avoid the LTS all necessary information has to be integrated into a visualization tool to support production planners in their process of decision-making. Hence, besides the presented requirements to deal with the LTS itself, a visualization would require the following points to deal with human behavior, which are explained below:

a. it has to be intuitively understandable.
b. it has to give a quick overview of main system KPI's.
c. the anticipated future development of KPI's such as due date reliability or lead times has to be shown.
d. all visualizations have to be interactive.
e. a visual or text based warning system has to be included.

The meaning of each bit of information should be well known to a user or (a) intuitively understandable such as traffic light colors. Judgment errors would be more likely if decision makers need enhanced training to understand and interpret given information. This also means that only a selection of the most relevant information should be included to avoid overstraining. Thus, actual system states should be represented only by an (b) overview of the main system KPI's, such as lead times, due date reliability, and WIP levels. The visualization of (c) anticipated future developments of selected values would instantly show systems behavior, thus avoid misinterpretation and overreaction. However, further research is needed in the field of anticipating the resulting due date reliability after planned lead time adjustments. Knollmann and Windt developed an extension of Equation 1 to calculate the resulting due date reliability in the long-term (Knollmann & Windt 2013a), but the calculation and visualization of the short-term due date reliability development is still open. Nevertheless, the (d) interactive visualization of optional value settings would facilitate the decision-making process in term of choosing the 'optimal' strategy. Also, to keep planners from running into the LTS, a (e) visual or text based information box should be included that would generate instant feedback to the decision maker while adjusting values. Exemplary, a warning should indicate the possibly wrong decision, if a planner sets the new planned lead time to a higher level, although it should theoretically be decreased (e.g. due to a reduction of the corresponding WIP level).

The following chapter presents a first attempt to combine the derived requirements in one visualization-tool, which would support planners in the process of decision-making.

5. Methodology to Prevent Human Mistakes of Overreaction or Misinterpretation

Recent research on the LTS showed the need of a methodology to prevent human mistakes of overreaction or misinterpretation of information in the process of decision-making. The previous chapter summarized requirements for a strategy roadmap to deal with the LTS. These requirements have to be transferred into a visualization-tool to support planners and minimize the probability of wrong decisions in terms of a decreased system performance. Figure 4 shows a screenshot of a first attempt to combine the derived requirements in one interactive user interface.

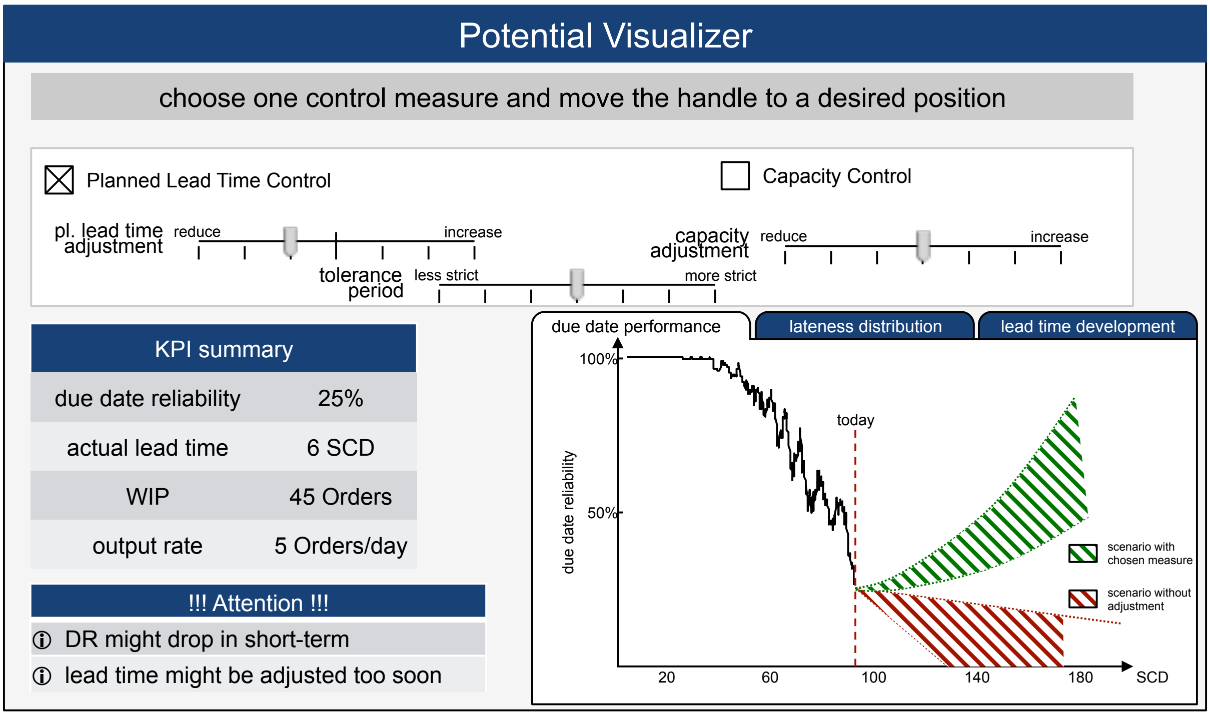

Figure 4. Screenshot of a user interface with real time scenarios of anticipated KPI-developments

Initially a user has to choose between the two control options 'planned lead time control' and 'capacity control' and move the handle of the particular controller to the desired position. The tolerance period affects the results of both control strategies. A stricter due date tolerance would lead to a more sensitive system behavior in terms of disturbances. The KPI summary gives an overview about the actual logistic performance without rating them. The most attention should lie on the instant feedback box in the lower right corner of the user interface. Exemplary, three values were chosen to demonstrate the choice of the user between different visualization options. Here, the due date performance development is shown over time until 'today'. Depending on the chosen control strategy and the desired adjustment, an instant scenario corridor would visualize the most likely development of the value. It would also be possible to visualize a corridor of the anticipated development if no actions are taken. Both corridors are so far schematic drawings without underlying calculations. Taking into consideration the likelihood of triggering the LTS, special care has to be taken to visualize or inform a user about possible risks or things that should receive attention. This is implemented in the 'attention' box, which would display necessary information depending on the choices of a user. Another strategy would be to directly implement limits into the adjustment controllers, e.g., by making it impossible for a user to adjust too often or to choose illogic or infeasible values (e.g. capacity adjustment would exceed the maximum capacity). Potentially, a variable color scaling would also help. Also, pop-up windows could be integrated to give more information when a user clicks on a value or a word. However, the biggest benefit of the presented methodology is the anticipation of future states rather than only presenting the actual or past situation. The interactivity moreover gives an instant feedback to a user what happens if an adjustment is performed with his current choices.

6. Conclusion

The aim of this paper was to determine requirements and to derive an initial concept of a methodology that aims to prevent human mistakes by overreaction or misinterpretation in scope of the LTS. The case study showed the need for such a methodology. Planners tend to adjust planned lead times even if no transparency about actual system states is given. The complexity of production processes makes it impossible for planners to anticipate future scenarios with a suitable accuracy. Moreover, the brief introduction into the research on human behavior revealed the strong influence of intuition on the decision-making process, which also includes judgment errors. Thus, a methodology to avoid the LTS has to consider human behavior and situation sensitive strategies. The corresponding framework was finally transferred into a first concept of a visualization-tool. The aim of the visualization-tool is to support decision makers to make the right decisions at the right time. It includes the visualization of possible KPI future patterns in a transparent and interactive user interface. However, this user interface is in a concept stage so far and further research is needed on each of its segments. Exemplary, the flexibility of capacity adjustments is restricted to, e.g., short-term extra shifts (see also (Breithaupt 2000) for the theory of envelope curves of capacity flexibility). Moreover, the quantification and definition of 'optimal' adjustments and impacts of adjustments are still rarely investigated. Thus, further research is needed on the LTS to prevent planners from making wrong decisions.

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An Investigation of Production Changeover Time Reduction in Supply Chain Oriented Manufacturing Plant and Sustainability to Improve the Plant Performance

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Abstract

The supply chains for manufacturing systems have become more complex with increasing customer requirements on a global scale. The situation becomes more complex in the context of market demands, which change daily or weekly, and the corresponding responsive changes across production lines, i.e. product changeover (setup time/start-up time). Such a situation often results in wastage of resources: for instance, time consumption, wastage of materials and other resources, and the reconfiguration of the production line, for example.

The ability to implement rapid changeover on a product line in switching from one product to another is the keys to increasing production line flexibility. Thus far, most of the research on short changeover has focused on conventional methods, such as the use of Single Minute Exchange Dies (SMED), internal and external activities, and time-dependent activities. This paper proposes a unified model for changeover time reduction using conventional and new methods with a sustainable design in order to reduce product changeover complexity. Through the proposed model, sustainability is taken into account by including resource utilisation, energy consumption and waste generation, etc. The proposed approach will not only improve machine utilisation but will also result in improved flexibility and reductions in wastage throughout the whole production facility.

Keywords: Production changeover, Sustainable manufacturing, Manufacturing supply chains, Plant performance.

1. Introduction:

Over recent decades, rapid changes in manufacturing technology, and advanced and global competitiveness have given customers the opportunity to seek out customised products with special details that fit with their desires and use. This demand from individual customers has created a new trend of production in industries (Almomani, Abdelhadi & Mumani, 2013). Manufacturers are now required to produce small batches with shorter lead times in order to meet customised demand. Companies are doing their best with short possible responses to fulfil their customers' requirements in order to be at the forefront of their competitors.

Producing various products on single production line makes process more complex, and result in increased human errors and impacts on plant performance (Hu, Zhu, Wang & Koren, 2008). In order to incorporate quick changes and quick responses with customer, rapid changes in the production line are required in terms of switching from one product to another. Producing different types of product in smaller batch sizes results in a larger number of changeovers.

A changeover in production terminology means that the manufacturing process changes from one type of product variant to another. Due to this changeover, there are many potential losses incurred in terms of raw materials, products, time and utilities, such as energy or water. The term Time, Resource and Waste (TRW) will be utilised in this regard. The importance of short changeover times has always been critical for manufacturing companies, especially automotive companies (Ferradas & Salonitis, 2013).

In the early-1960s, Shigeo Shingo introduced 'Single Minute Exchange Die' (SMED). Many companies have continued to use conventional methods of changeover time reduction through (SMED), with most researchers usually working around the SMED approach. Most researchers work on the basis of SMED, reduction of complexity, simplifying the changeover steps, transferring internal activities to external ones, etc. However, there is lack of research centred on reducing production changeover in methods besides those mentioned.

In this paper, the research is presented in an effort to reduce the changeover times whilst ensuring sustainability, and to investigate their interlinks with each other by using both conventional and new methods. A sustainable society must live within its means and use energy and material in a way that does not compromise living standards or the health of future generations (Smith & Ball, 2012). Accordingly, in this paper, a couple of different methods are introduced in an effort to improve changeover time reductions, i.e. time, resources, and waste reduction (TRW). Our focus is centred on controlling all of these elements whilst achieving sustainability. We will also concentrate on reducing different types of complexity in the product changeover time reduction process.

2. Literature Critical Review

In an ideal manufacturing world, one production line is used to produce a single product without changeover; unfortunately, however, the ideal manufacturing world does not exist. Unquestionably, markets are highly volatile, demand fluctuates, and inventory costs increase in such a way so as to support and achieve production target. The best changeover is no changeover (Keith, 2012).

Changeover frequency involves the substitution of machine components so that alternative products may be manufactured (Mileham, 1999). The frequency of changeover increases as customer demands change, due to which production changeover (COs) takes places. During product changeover, manufacturers need to setup machines or complete machine changeovers, which results in resource wastages during the process. The most comprehensive measure of **machine setup** or **machine changeover** time is the time spent between the production of the last part of one lot or one type of product, and the production of the first part of the next lot or a different type of product. The time during—through which, notably, no finished good part or product comes out of the production line (Steudel & Desruelle, 1991)—constitutes a waste of resources. Setup involves the removal of the old tooling and equipment, along with the replacement of new tools and equipment, followed by a rough cut setting of the various adjustment required (McIntosh, Culley, Mileham & Owen,2001). To set up efficiently, operators require fast access to accurate processes, equipment, the right tools and work holding equipment, and efficient machine tools.

2.1 Conventional Methods of SMED:

There are several publications and case studies available on the ways in which setup times can be reduced in existing situations. Essentially, most of the approaches are driven by Single Minute Exchange Die (SMED) (Goubergen and Landeghem, 2002), which is very useful in eliminating or reducing waste, and is widely used by manufacturers. The use of the SMED approach is not limited to only one type of industry, but rather is widely used by the manufacturing industry. The SMED technique was introduced and applied to a jet machine in order to achieve a setup time reduction of less than 10 minutes; similarly, a 35% setup time reduction has been achieved in an automotive battery assembly line by implementing the conventional SMED method (Almomani, Abdelhadi & Mumani, 2013).

2.2 Complexity of Production Changeover:

Complexity increases when manufacturers decide to manufacture different types of product on the same production line with few changes. These changes can take a long time and can waste resources. Complexity is defined as a measure of uncertainty in achieving the specified functional requirements. The complexity of manufacturing systems is also defined as the expected amount of information needed to describe the state of manufacturing system (Smart, Calinescu & Huaccho, 2013).There are different types of complexity, which we need to find and categorise; these can be categorised as time-dependent complexity and time-independent complexity (Suh, 2005). Increases in complexity may provide various advantages in the marketplace in terms of an increased number of products and options that a manufacturing organisation can offer to its customers system (Smart, Calinescu & Huaccho, 2013).

2.3 Internal and External Activities:

Different steps and activities are involved in setting up a machine; these can be classified as internal and external activities. It is very important to identify internal and external activities: internal activities are those activities that cannot be performed whilst machines are running; external activities can be performed if machine is running (Suh, 2005). In order to make every effort to reduce machine setup time, we need to note and understand every activity involved in the machine setup time. At this point, once we have all lists of activities, we then need to identify internal activities and accordingly take steps to transfer them to external activity. If we are successful in transferring any internal activity to external activity, this then will be achieved without stopping machines, which will reduce machine setup time.

For example:

External setup activities:

- Getting new die from warehouse/store
- Getting raw materials for Product B
- New fixture preparation to install (if any)
- Operator ‘wait’ time for forklift or any materials, or anything else.

Internal setup activities:

- Unclamping and the removal of existing fixtures
- The cleaning of the production line
- The dismantling of jigs and fixtures
- Fixing new fixtures
- Removing waste.

Existing Setup

Separate Internal and External Steps (From Product A to Product B)			
From Product A	**External Setup Time: 08 Minutes**	**Internal Setup Time: 10 Minutes**	**To Product B**

Figure 1: Existing Internal/External Time

The schedule/step sequence of a machine setup or changeover usually means that each step varies from the next; however, we need to identify, wherever possible, and implement two or more parallel steps/activities in order to save time. If we assume that each activity takes 2 minutes, if we dismantle jigs and fixtures after removal, then we will be able to transfer 1 activity from internal to external, meaning the production line will stop for 8 minutes rather than 10 minutes.

After Change

Separate Internal and External Steps (From Product A to B)			
From Product A	**External Setup Time: 10 Minutes**	**Internal Setup Time: 8 Minutes**	**To Product B**

Figure 2: Proposed Internal and External Time

3. Research Objectives

The aim of this paper is to develop guidelines to establish actual production losses due to product changeover in an effort to minimise losses in the manufacturing processes, e.g. time, material and energy.

The foremost objective of this paper is to reduce product changeover (CO) time with sustainability. In order to achieve this objective, we first need to identify each and every step where losses have occurred. For instance, we need to study, identify and record each activity between the production of the last finished good of the first production lot and the first product of the next finished product. In this example, we need to study the shutting down of the machine, the disassembly of jigs and fixtures, the cleaning of the production line, the washing up of the production line, and the fixing of jigs and fixtures, etc.

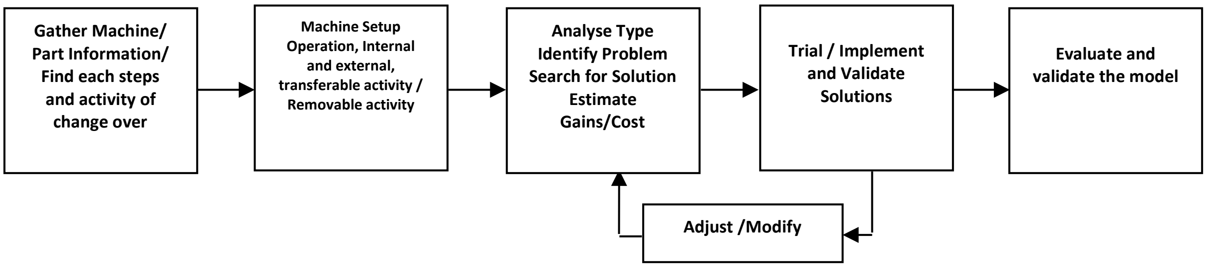

Figure 3: Product changeover sequence model

It is imperative that designers design machines in such a way that makes the setup process as easy as possible in order to minimise mistakes, as well as with lesser technical skills. By so doing, machine operators will find carrying out setup process in a fast working environment a relatively simple process. In this way, the operator can carry out setup easily, with the following design rules considered during the design phase:

Usage of lighter materials helps to reduce non-changeover parts. As described by Goubergen (2002), the use of lighter materials makes it simpler to reduce the number of mechanisms, and so efforts should be directed towards eliminating or reducing non-changeover parts.

We also need to study the rationale and justification behind product changeover. Can we reduce the number of product changeovers as a minimum so that we do not compromise on quality and production target? Unnecessary elements should be eliminated in order to avoid the usage of resources, i.e. stop or stand by equipment when not in use. We need to look for companionable waste output and demand in an effort to understand where and when waste are generated, as well as whether it can be used as resource input elsewhere in order to ensure its proper utilisation (Despeisse, Oates & Ball, 2013). One of the objectives is centred on determining a processing sequence so as to minimise the total setup time of a production line (Lee, Liao & Chao, 2012).

The overall objective is to eliminate or reduce loses, i.e. time, energy, raw material waste, utilities, etc., as well as to identify how far we can go in terms of achieving resource efficiency.

4. Research Area and Description

During the last few decades, new technologies have been introduced, and global competition has been increased dramatically. Customers’ requirements and demands are also changing rapidly. In this competitive global manufacturing world, customers are looking for customised products and, as a result, the varieties of products have become very high. Manufacturers are now looking to manufacture different variants of a product or different products on a single production line. As variety gets high, the manufacturing process becomes more complex. Accordingly, in an effort to compete in the competitive global market and thereby meet customers’ demands, manufacturers need to switch from one product to another product on the same production line. This means more production changeovers, with many changeovers meaning greater losses and more down time. Furthermore, this also increases the importance of changeover time and losses.

Changeover time reduction with sustainability is the key focus of this paper, as well as emphasis on minimising product loss, raw material waste, and time losses, as well as waste concerning utilities, such as energy and water. When a product changeover take place, it generally includes a number of steps, such as shutting down, obtaining tools, positioning work in process material, returning tools, disassembly, cleaning, washing, setting required jigs and fixtures, adjusting tools, starting up again, and reassembling all steps, which requires a significant amount of time, energy and resources, and produces waste (Sherali, Goubergenn & Landeghem, 2008).

There are several characteristics and boundaries concerning setup activities that need to be scheduled, some of which need to be carried out one after the other, with some also needing to be carried out randomly and not in sequence, whereas some can be performed simultaneously (Sherali, Goubergenn & Landeghem, 2008). Furthermore, we must also take into account labour constraints in an effort to figure out how many workers are available to achieve a balanced workload between workers and accordingly to define activities.

Everyone in the changeover team should know exactly what to do, when to do it and how to do it, and the skills required to perform each task, along with the right materials at the right place and at the right time. All tools and equipment should be well-maintained and thoroughly prepared. The main goal is to fully understand the complex situation, parameters and interactivities governing both waste-generation, and its control and mitigation.

So far, conventional methods have been adopted in order to reduce product changeover time; now, however, is the time to move forward and introduce various new methods of product changeover time reduction, along with sustainability. It is difficult to reduce machine setup time, especially on the automatic production line, and there is a need to reduce resource utilisation so as to become more eco efficient.

5. Design of the Methodology Approach

In order to remove or reduce complexity in the product changeover of the system, data is required in order to be able to quantify results. Changeover activities are divided into **internal setup** and **external setup**: internal setup activities cannot be performed without stopping the machine, whilst external setup activities can be performed whilst the machine is running.

Process factors are classified as control factors and noise factors: control factors, as the name implies, are those factors that can be controlled easily; noise factors, on the other hand, are difficult, expensive or impossible to control (Karasu, Cakmakci, Cakiroglu & Ayva, 2014).

One of the most important elements is that identified potential losses are considered simultaneously through the use of developed tools in order to derive an instant decision on key losses and changeover strategies. If we can reduce downtime due to changeover, then product capacity will increase automatically. After receiving information on all work and steps carried out in the changeover period, we need to measure and record the time of each activity, and categorise all activities into two sections, i.e. one is **internal setup** and another is **external setup**. Each activity then can be grouped into sub-groups.

Potential improvements in the changeover may occur either by varying the sequence of conducting tasks without changing the way in which tasks are done, or otherwise by altering the sequence of the existing task so that it can be completed quicker (Almomani, Abdelhadi & Mumani, 2013).

Below is the product changeover model.

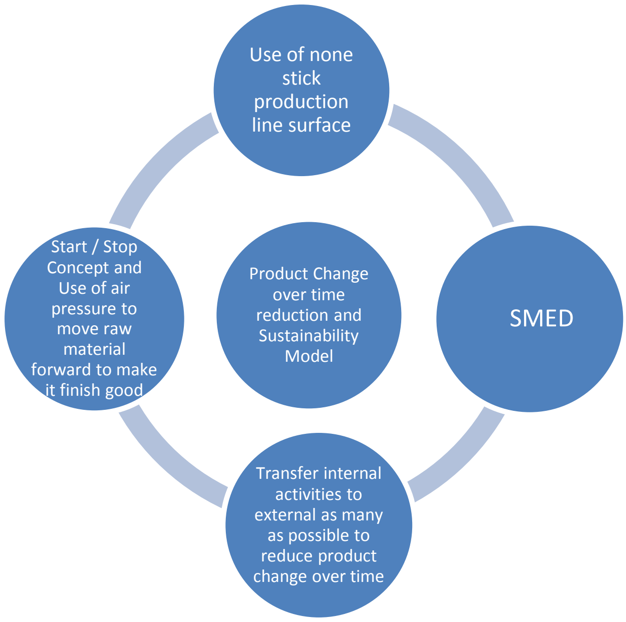

Figure 4: Product changeover time reduction model

Sustainable Manufacturing Tactics

Waste-reduction tactics focus on waste outputs in an effort to reduce waste and losses or otherwise to maintain the value of the output through adequate processes or techniques and management. These improvements are considered relatively easy since they allow quick savings in resources and costs compared with the efforts invested (Despeisse, Oates & Ball, 2013). Some new ideas to save resources are explained below.

- **Start/Stop Concept**

Cost of energy is one of the major aspects of total cost per product. We can introduce the Start/Stop concept like a car Start/Stop to reduce energy consumption and to reduce carbon footprint. This will save energy during production changeover or the production line. Machines need to be in running mode only when producing goods, and should be stopped automatically if not in use for any reason in an effort to reduce energy consumption. We also need to know where to introduce the Start/Stop concept. For example, ovens can take several minutes or hours to reach the specified required temperature, meaning the Start/Stop concept would not be suitable for ovens. On the other hand, the Start/Stop concept can be introduced in regard to smaller machines that can start and run with no time wastage.

The below graph provides an example of the Start/Stop concept. Energy consumption is 0 when the production line is automatically stopped.

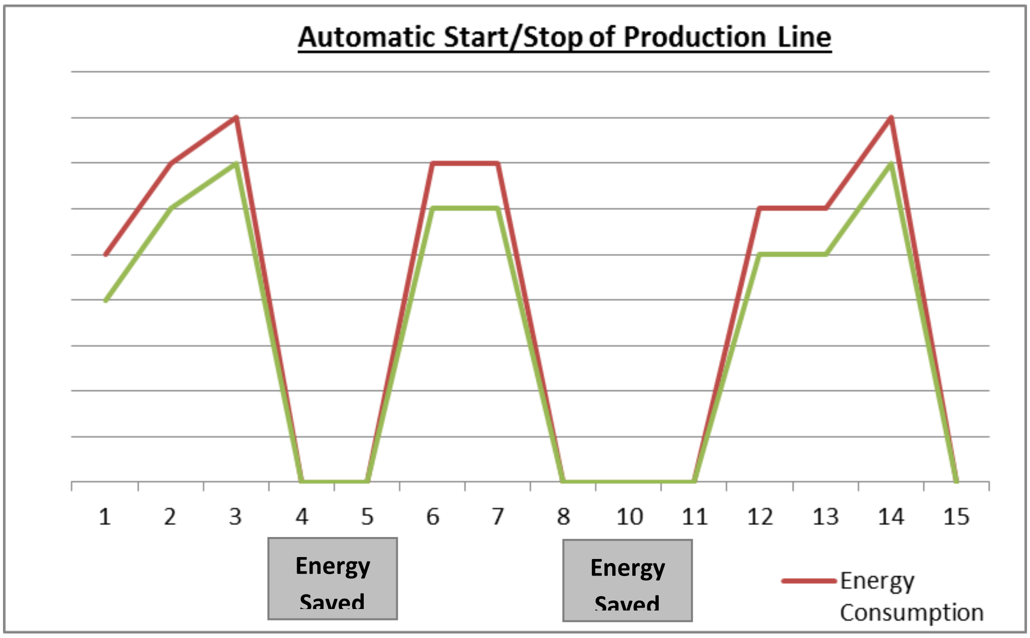

Figure 5: Automatic Start/Stop production lines

- **Smart Setup Time Reduction**

a) Non-stick production line surface to reduce cleaning time and waste or raw material

During production changeover, raw material waste takes places. In an effort to eliminate or reduce raw material waste, we can design and introduce the non-stick surface production line; this can act as a trial on a small production line. Through the use of the non-stick surface production line, raw materials will move forward as the production line moves, and materials can be used on the finished goods produced. This will eliminate or reduce waste or raw materials, and can increase the number of products manufactured. By using this method, there will be savings in terms of time for cleaning or in terms of materials from the production line. As a result, product changeover times will reduce.

For example, in regard to product changeover, we need to carry out the activities detailed in the list below. Here, we will assume that each activity will take place for 1 minute. If we have 10 activities, then the total changeover time will be 10 minutes.

- Dismounting jigs and fixtures
- Removing materials from the production line
- The cleaning of the production line
- The cleaning of tips, etc.
- Assembling new jigs and fixtures
- Tool adjustment
- Obtaining tools
- Starting up again
- Disassembly
- Reassembling all tools.

If we design the production line in such a way that raw materials do not stick to the production line, then we do not need to remove raw materials from the production line; we still need to clean it, but there may be the possibility that it may take less time when compared with before. We can save at least 1 minute of time and reduce this to 9 minutes in total, meaning the total changeover time can be reduced by 10%. On top of time-reduction, raw materials will also be saved. Quantity for raw materials saved varies from one product to the next.

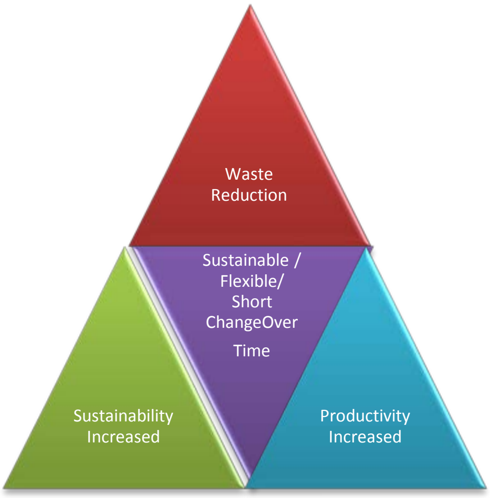

Figure 6: Sustainable/Flexible/Short Changeover time

b) Use of air pressure to reduce waste

During production changeover from one product to another product, material is left on the production line, which is usually wasted. In an effort to eliminate or reduce raw material waste, air pressure can be used to move raw material forward, thus helping to make it a finished good. It will also help to produce more products, and will reduce the waste of raw materials whilst also helping to reduce cleaning time to remove material from the production line.

The following losses, which are not limited to the below, need to be identified and further explored with the passage of time as all efforts can help to improve plant performance.

6. Further Analysis and Results

The product changeover time reduction process, along with sustainability, is complex for supply chain-oriented manufacturing plants. Manufacturers play a key role in aiding changeover towards sustainable developments. In the case of product changeover time reduction, sustainability should be considered as a key element for manufacturing organisation, and its importance will increase in the future with the passage of time. Manufacturers still use conventional methods, such as Single Minute Exchange Die (SMED), to reduce production changeover time where possible, along with the above proposed ideas. By designing the assembly line in such a way, where raw materials move forward automatically or by using air pressure to push forward raw materials, TRW (Time Resources and Waste) will be reduced.

As mentioned earlier, if non-sticky production line surface is used, then raw materials will not stick to the line. As a result, the time consumed on removing raw materials from the production line can be saved, amounting to 10% in total production changeover time. By so doing, raw materials can also be saved, which can be used to manufacture finished goods and to improve plant performance.

As mentioned above, cost of energy is one of the key components associated with total product cost: if we can use the concept of Start/Stop on the production line, energy consumption will be reduced, as will per unit cost of production.

Detailed methodologies are required in order to aid manufacturers in analysing their operations, and identifying and implementing improvements in their factories to reduce product changeover time, also keeping in mind environmental impacts. There is the potential to eliminate or further reduce product changeover time with the evolution of technology, which requires exploration in the future.

7. Concluding Remarks

In this paper, setup time reduction methods have been addressed, with short setup times recognised as a necessity nowadays across all types of industry. There exist various good methodologies able to reduce such setup times in existing situations. Through this paper, a new approach for setup time reduction is proposed, along with sustainability and conventional methods. Design is an important activity in the reduction of changeover times in the case of improvements to existing productions lines or the design of new production lines. Improvements to existing production lines, which are based on a combination of both conventional methods (SMED, transferring internal and external factors, etc., and new methodologies (non-stick production surface, Start/Stop, etc.) all typically result in lower changeover times.

The results illustrate the benefits of implementing the proposed approach, which include reducing setup times, increasing machine utilisation, reducing raw material waste, reducing usage of power, and improving productivity.

Further research can be carried out in greater depth in an effort to identify new tools and developments so as to eliminate or further minimise changeover time reduction, as well as to achieve improved sustainability.

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Lead-Time Hedging and Coordination in Prefab House Construction Supply Chain Management using Game Theory

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ABSTRACT

Prefabs are used increasingly to simplify the building process on-site. And timely delivery of prefabs attracts extensive attention, for tardiness delivery is enormous nowadays. In order to solve this problem, the construction site manager prefers to inform the prefab manufacturer an earlier due date. This strategy is called "lead-time hedging". However, this strategy adds much pressure to the prefab manufacturing department, for their production time is shortened. Thus, the conflict generates. To solve this conflict, an "additional money" is involved and a Stackelberg game where the prefab manufacturer acts as a leader and the construction site department serves as a follower is studied in this paper. Also, a cost sharing contract is discussed to balance the profit for each department. We find out that the coordination scheme reduces the lead-time hedging amount without sacrifices each department's profit. Also, other insights are obtained from comparative analysis and numerical studies.

Keywords: Lead-time hedging, Prefab house construction, Supply chain coordination, Game theory, Cost sharing contract.

1. INTRODUCTION

In recent decades, there is a growing tendency to use prefabs in a construction site. A plenty of research has been done to unveil the advantages toward applying prefabrication (Ho, 2001; Hsieh, 1997; Tam, Tam, Zeng, & Ng, 2007). For example, the material cost and the building duration can be significantly reduced. However, although lots of benefits can be brought from using prefabs, the management of it is far from satisfactory, for the risk of failure to meet expected lead-time is enormous (Walsh, Walsh, Hershauer, Tommelein, & Sawhney, 2002). In this way, time and cost savings from adopting prefabs will wither away. In order to prevent tardiness delivery the construction site manager informs the prefab manufacturer an earlier due date. However, this lead-time hedging strategy adds much pressure to the prefab manufacturing department. Thus, it is necessary to find out a scheme to coordinate these two departments. The main thrust of this coordination scheme is to take advantages of lead-time hedging strategy and balance the profit for each department.

There are three departments involved in the prefab supply chain. As the figure 1 shows, the prefab manufacturing department produces prefabs. The logistics provider transports the finished prefabs from manufacturing yard to the construction site. And construction site is te final destination where builders assemble those prefabs.

Actually, lots of uncertainties exist in the prefab supply chain such as machine break down, unavailable buffer space, bad weather conditions which hamper the on time delivery of prefabs.

Unfortunately, further unfavourable impacts will be brought from tardiness delivery. Actually, shortage of prefabs accounts for the major delay of the on-site assembling process. According to the case studies on Last Planner implementation, defective material deliveries account for 8-25% of the non-completed tasks (Ala-Risku & Kärkkäinen, 2006; Koskenvesa & Koskela, 2005). Even worse, shortage of building materials is the major factor which leads to cost overrun of the total project(Kaming, Olomolaiye, Holt, & Harris, 1997). Hence, it is justifiable to pay closer attention to on time delivery of prefabs since there is a good potential for savings from less double handling and other no value added activities. In practice, for the sake of hedging impacts from unforeseen events, construction site manager prefers to inform the prefab manufacturer a shorter lead-time. This kind of strategy is referred as “lead-time hedging”.

Lead-time hedging is a strategy which has been commonly adopted in manufacturing and retailer departments (Hu, Guan, & Liu, 2011; Palaka, Erlebacher, & Kropp, 1998; Shapiro, 1977).Limited literature can be found for solving the tardiness delivery of prefabs in a construction site using lead-time hedging strategy. In this paper, the definition of lead-time hedging is specified as follow. The actual due time of using a prefab is t_2 which is known by the construction site manager. The manager making orders at time t_0 and informs the prefab manufacturer a pseudo due time t_l which is ahead of t_2. In this way, the lead-time of producing a prefab has been reduced from t_2- t_0 to t_l- t_0.This paper only considers the interference between prefab manufacturing department and the construction site department.

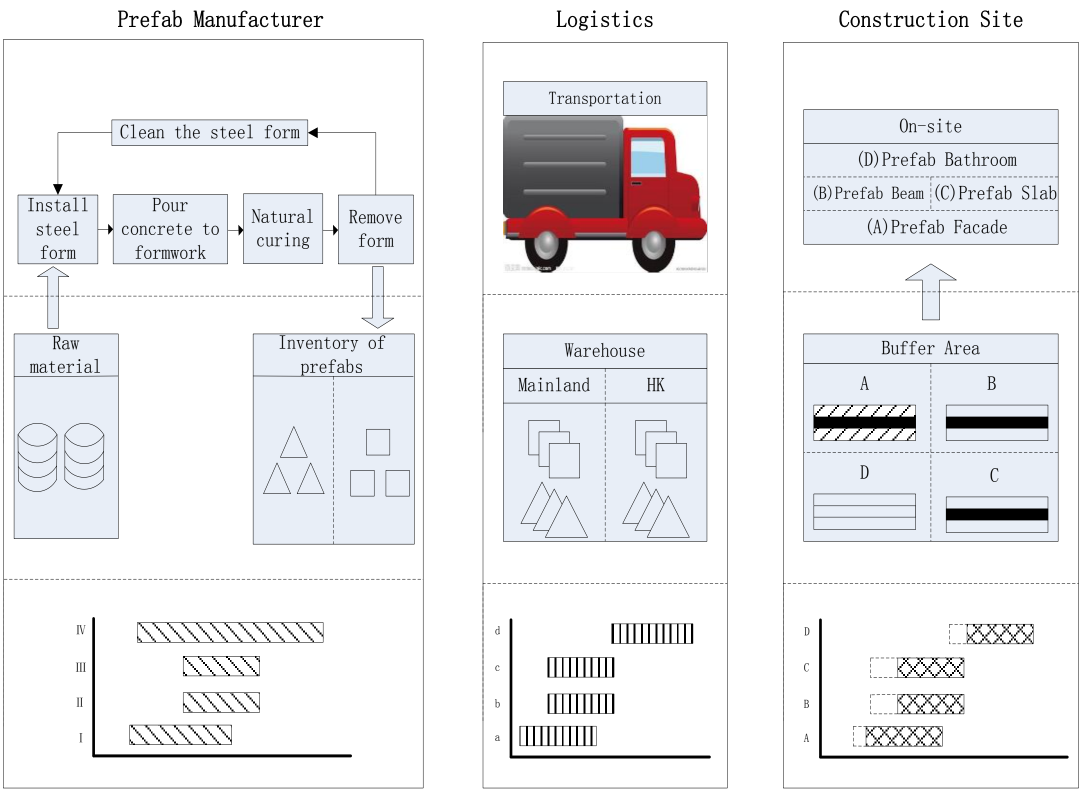

Figure 1. The prefab supply chain

The significances for the existence of lead-time hedging for the construction site managers is that they always concern about whether the required prefabs can be finished and delivered in time. If not the construction process will be hampered, and therefore, time and cost overrun will happen sequentially.

Since lead-time hedging strategy increases the possibility of on time delivery, double scheduling cost for lacking prefabs or expensive express delivery can be avoided. In addition, the possibility for lost labor can be minimized. Since prefabs are heavy, bulky components which need to be hoisted by cranes, there is a great potential for savings from renting expensive cranes (Pheng & Chuan, 2001).

However, lead-time hedging strategy scarifies the interests of the prefab manufacturing department. This strategy pushes the prefab manufacturing department to produce prefabs within a shorter lead-time, and thus, extra investment for hiring more workers or increasing capacity occurs. Thus, the construction site department needs a longer lead-time hedging amount to increase on-time delivery probability while the prefab manufacturer prefers a shorter one to reduce extra investment. On this account, the conflict exists. The main thrust of this research is to find out a coordination scheme which takes advantages of the lead-time hedging strategy as well as optimizes the profit for both departments.

Although it is a typical lead-time problem, some characteristics under this scenario substantiated the complexity of the problem significantly. Three features are discussed. To begin with, the construction site department is lead-time sensitive. This characteristic is similar with customers' preference in a marketing circumstance (Blackburn, Elrod, Lindsley, & Zahorik, 1992; Smith, Bailey, & Brynjolfsson, 2001). Customers are willing to pay a reasonable price premium for a short lead-time (So & Song, 1998). In this way, the lead-time and the price are interdependent variables. Different from previous work, our research focuses on studying the trade-off of between these two variables. Secondly, the arrival of prefabs should successively in consistent with the building cycle. Neither late nor early delivery is favorable, for any disruption at any point would impact the entire process. Thirdly, uncertainties exist in both prefab manufacturing department and construction site. On the one hand, the probability of on time delivery is not 100% for unforeseen events will inevitable influence the production and delivery process. On the other hand, the starting date of a building activity is uncertain, for any delay or early start is very common in a construction site due to factors such as festive season, lack of labor or machine. Therefore, the probability distribution of a project's starting time should be taken into consideration.

Timely delivery of prefabs is of utmost important for the construction site, for construction duration and material cost overrun can be easily triggered by shortage of materials (Kaming *et al.*, 1997). In recent year, considerable research has been done to study tardiness delivery problems. Lots of literature can be classified into two branches. The first branch focuses on the material shortage problem in the building industry. Many possible solutions have been proposed which include the JIT management of building materials (Bertelsen & Nielsen, 1997; Pheng & Chuan, 2001), pre-positing material inventory among the supply chain (Ben Naylor, Naim, & Berry, 1999; Walsh et al., 2002) and schedule the material requirement amount while taking the process rate into consideration in the initial stage (Caron, Marchet, & Perego, 1998).

The second branch is about solving material shortage problem under a marketing circumstance. Lead-time hedging strategy and coordination scheme have been introduced as effective ways to enhance on time delivery probabilities as well as maximize the profit for both manufacturing and retailer department (Hu et al., 2011).
However, little literature can be found for solving the tardiness delivery problem of prefabs with lead-time hedging strategy and the corresponding coordination scheme is also limited.

In this paper, we try to find out a coordination scheme to solve the conflict between prefab manufacturing department and construction site department which is brought from adopting lead-time hedging strategy. Firstly, we introduce two decision variables. The one is the lead-time hedging amount which is determined by the construction site department and the other is the additional money which is charge by the prefab manufacturing department to compensate its extra overwork cost. Secondly, we carry out a theoretical analysis to compare lead-time hedging amount, total profit and individual profit of each department under unilateral decision model, global optimal model and the Stackelberg game model. In addition, a cost sharing contract is introduced to balance the profit change for each department under the Stackelberg game model. Later on, numerical studies are proposed to demonstrate that Stackelberg game model together with cost sharing contract successfully coordinate the prefab supply chain.

In this paper, three lead-time related costs are introduced in this paper. Specifically, the additional money and the holding cost are increasing with lead-time hedging amount while the tardiness penalty is decreasing with it. A Stackelberg game model was studied. In this model, the construction site department acts as a leader who decides the lead-time hedging amount while taking the prefab manufacturing department's behaviour into consideration on the first stage. And then the prefab manufacturing department serves as a follower who decide the additional money and aims at maximized its own profit on the second stage. Later on, we introduce a cost sharing contract in which some fraction of additional money and tardiness penalty which was initially paid by the construction site department will be shared by the prefab manufacturing department.

The rest of paper is organised as follows. Section 2 gives out a literature review under three branches. Section 3 describes the problems, points out model assumptions and notations as well as introduces the model formulation. In section 4 a unilateral decision model is introduced. In this model, the construction site department is powerful enough to decide the lead-time hedging amount to maximize its own profit. Section 5 points out a global optimal model in which each department has equal power and the aim is to maximize the entire profit. Later on, in section 6 a Stackelberg game model is presented and a cost sharing contract is studied. Section 7 provides the comparison analysis towards the performances of each model. Numerical studies are used to compare the total profit and the verified profit of each department. Section 8 concludes the paper and points out that the proposed Stackelberg game model together with cost sharing contract can successfully solve the conflict caused by lead-time hedging strategy.

2. LITERATURE REVIEW

Using lead-time hedging strategy to cope with material shortage problem has attracted considerable attention in recent years. This increasing attention seems to be from the fact that the on time delivery probability of products can be enhanced by informing the manufacturer a shorter lead-time. Also a growing number of researchers studied strategies to cope with tardiness delivery problems, since using prefabs brings lots of benefits(Ho, 2001; Hsieh, 1997; Tam et al., 2007) and there is an increasing potential for the prevalent use of them (Jaillon, Poon, & Chiang, 2009). Previous literatures can be classified by three schemes. The first one addresses strategies that can be used to reduce the lead-time. The second branch is about the scheme to coordination the conflict caused by lead-time hedging strategy. The last one is about the mathematic methods applied to solve the proposed coordination scheme.

2.1. Practical strategies to reduce the lead-time

The main thrust of reducing the lead-time is to hedge uncertainties from the manufacturing process and consequently enhancing on time delivery probability. Reducing lead-time requires the manufacturer to produce within a shorter time period. Actually, crashing work is an effective way to fulfill the order. However, addition investment should be paid to hire more workers or enlarge capacity. Other strategies have been found from pervious literature. Some researchers have studied the application of just-in-time (JIT) philosophy in the manufacturing sector and found out that production time can be greatly reduced, since no value added activities can be reduced (Akintoye, 1995; Hopp, Spearman, & Woodruff, 1990). Other literature pointed out that reducing delivery time with JIT management system streamlines a supply chain (Ala-Risku & Kärkkäinen, 2006; Bertelsen & Nielsen, 1997; Pheng & Chuan, 2001). Pre-positing inventory is another way to reduce the lead-time (Ben Naylor et al., 1999; Walsh et al., 2002). This strategy is to carry standard components which can be assembled directly at the decoupling points so as to offer speedy response. To this end, extra investment which derives from applying JIT technology, renting warehouse and overwork cost.

2.2. Lead-time hedging and coordination with "internal price"

Lead-time reduction is a general problem which has been studied in a marketing circumstance. Considerable literature can be found to solve the conflict caused by lead-time hedging strategy. Since this hedging strategy adds much pressure to the manufacturing department and consequently leads to less profit (Shapiro, 1977), it is justifiable for a customer to pay price premium as compensation (So & Song, 1998). Charging "extra money" is a direct way to compensate the overwork cost and there is strong interdependence between price and lead-time amount.

Several works are related to our research, but with different emphasis. Different kinds of "internal price" have been studied. Hu et al. (2011)proposed a coordination model to reduce the lead-time hedging amount as well as increase system-wide profit. In their model, the manufacturing department charges the sales department a fair internal price to compensate their overwork cost for a shorter lead-time. Jiangtao, Jianjun, and Ge (2012)proposed a similar model. In their study, two strategies have been introduced to reduce the lead-time hedging amount. One is to involve a variable wholesale price which is an increasing function of lead-time hedging amount and charged by manufacturing department. The other involves delay compensation if the due date is exceed. There are also some other researchers studied the delay compensation (Dewan & Mendelson, 1990; Palaka et al., 1998; So, 2000; Vig & DOOLEY, 1991). In practice, tardiness penalty is an effective way to urge manufacturer to deliver products or services on time, since hitting the manufacturer in their pockets is a good deterrent effect against future late delivery (Pheng & Chuan, 2001). In Vig and Dooley's model, the tardiness cost is related to the delay probability and the total tardiness amount. Some scholars have taken the inventory cost into consideration; including Kachitvichyanukul, Luong, and Pitakaso (2012) who studied a coordination model in a integrate firm. A holding cost sharing rate between retailer and manufacturer was involved to achieve coordination. Some scholars use a fixed holding unit price and integrate it by holding period and amount (Hu et al., 2011; Jiangtao et al., 2012).

2.3. Mathematic models to coordinate the conflict caused by lead-time hedging

Limited literature has been found to cope with prefab's tardiness delivery problem with lead-time hedging strategy, not to mention the coordination scheme. The setting of the problem is in a decentralized supply chain, several papers studied the interference between manufacturing and sales department are related to our study. Pekgun, Griffin, and Keskinocak (2006) is the first to study marketing and production coordination for price and lead-time decisions. The propose of their work is to demonstrate that decentralized supply chain leads to lower profit and then pointed out that coordination can be achieved by involving bonus payment. In their model, the marketing department decides the price while the production department chooses the lead-time. Two Stackelberg games with alternative decision-making sequences have been studied to coordinate these two parties. Hu et al. (2011) also studied the decision making under a decentralized supply chain. Different from Pekgun et al. (2006), they formulated a leader-follower game model in which the supplier determines the promised delivery time and the wholesale price at the first stage and the retailer decides the retail price at the second stage. Each player take actions to maximize their own profit and a Stackelberg equilibrium has reached. Hu et al. (2011) studied a coordination scheme which involves an “internal price”. Nash and Stackelberg game model have been formulated to solve the conflict brought by lead-time hedging strategy. The firm’s total profit is increased. This result shows that even under a decentralized system the lead-time hedging strategy with an “internal price” provides incentives to both parties and consequently leads to centralized solution. A similar research was also conducted by Jiangtao et al. (2012). They proposed a definite function between lead-time and wholesale price which differs from Hu et al. (2011) who treat the relation between lead-time and price as indeterminate.

This paper studies lead-time hedging and coordination in a building industry. There are three contributions make this paper different from the above works. The first is the setting of the problem. Most of the papers studied the material shortage problem focus on a marketing circumstance. However, this paper aims at solving the prefab’s tardiness delivery problem in a construction site. Secondly, the lead-time hedging and additional price is treated as decision variables in this paper to coordinate the prefab manufacturing department and the construction site department. A Stackelberg game is also play in this paper. Moreover, a cost sharing contract is discussed to balance the profit change of each department under Stackelberg game model so as to achieve win-win coordination.

3. PROBLEM AND MODEL DESCRIPTION

3.1. Problem description

In this paper, a prefab supply chain with one construction site and one prefab manufacturing department is considered. A single kind of prefab component is ordered by the construction site manager with certain pattern and demand. The construction site manager prefers to inform the prefab supplier a pseudo lead-time which is prior to the actual due date for the sake of hedging uncertainties which cause late delivery. In this paper, we assume that the on-time delivery probability is increasing with the lead-time hedging amount. Actually, this strategy adds much pressure for the prefab manufacturer to overwork within a shorter time period and thus extra investigation will occur. In this paper, we assume that the prefab manufacturing department charges the construction site department an additional money for a shorter lead-time. And this additional money is increasing with the lead-time hedging amount. In addition, the construction site department should pay for the holding cost of the finished prefabs during the hedged lead-time. The total tardiness cost which is paid by the construction site department for the working hour lost is related to the probability of on-time delivery and it is also related to lead-time hedging amount.

In this paper, we focus on the interface of prefab manufacturing department and construction site department. The demand of each prefab order, denote as Q, is fixed and given by the construction site manager. Our work aims at finding out a scheme to make lead-time and price decisions to benefit both parties. Unilateral decision model, global optimal model has also been studied as benchmarks. Later on a Stackelberg game is played in this paper. In this model the prefab manufacturer acts as a leader while the construction site manager servers as a follower. The result of the Stackelberg game shows that the total profit of the entire supply chain is very close to the global optimal one and the lead-time hedging amount was decreased. However, this model scarifies the construction site department's profit. By this means, a coordination contract with tardiness and internal money sharing was discussed to balance the profit for each department.

3.2. Model assumption and notation

This section introduces the notation and assumption used in our study. We use the following notations throughout the text:

Subscripts

UD	denotes the unilateral decision the model
GO	denotes the global optimization model
SG	denotes the Stackelberg game model
Parameters	
P	fixed wholesale price per unit
Q	demand quantity
C	overwork cost per unit per time
S	fixed revenue per unit
H	holding cost per unit per time
T	tardiness cost per unit per time
β	cost sharing rate
d	the upper bound of the lead-time hedging amount
Decision variables	
l	lead-time hedging amount
w	additional money per unit

Assumptions

1. The holding cost *H* and late tardiness penalty *T* is exogenous given by a certain circumstance. In addition, $H>0$ and $T>0$.
2. The on-time delivery probability distribution function $P(l)$ a is continuous, increasing, and concave function of lead-time hedging amount *l*. That is, $P'(l)>0$ and $P''(l)\leq 0$. For the calculation convenient, in this paper, we assume the on-time delivery probability follows an exponential distribution. Specifically, for each lead-time hedging amount *l*, $P(l)=1-ae^{-\lambda l}$, $\lambda>0$, $0<a<1$. If $l=0$, which means that there is no lead-time hedging amount, then $P(0)=1-a$. As $l\rightarrow\infty$, the probability of on time delivery is almost 1.
3. The construction site department has to hold the finished prefabs during the hedged lead-time.
4. The tardiness penalty occurs when the required prefabs arrived later than the actual due date.
5. In this paper, we assume that the prefab manufacturing department is already fully loaded and any shorter lead-time order will trigger additional input.
6. No order will be cancelled due to late delivery. That is the construction site department will wait for the ordered prefabs and pay for tardiness penalty. In section 6, a cost sharing contract including this tardiness penalty between construction site department and the

prefab manufacturing department is studied. And this assumption is reasonable since the manufacturing department is also responsible for the late delivery.

7. The fixed part of manufacturing cost, ordering cost and so forth are ignored since they has nothing to do with the lead-time decision.

4. UNILATERAL DECISION MODEL

In the unilateral decision model, the construction site department is powerful enough to make lead-time decision to maximize its own profit. Without coordination scheme, this model scarifies the profit of prefab manufacturing department. The construction site department would choose a proper lead-time hedging amount to balance its input and output. The profit function for the construction site department is shown below:

$$\Pi_{OS}^{UD}(l) = SQ - PQ - HQ\int_0^l (l-t)dP(t) - TQ\int_l^{\infty}(t-l)dP(t). \quad (1)$$

After the prefabs have been received and assembled on site, the construction site department will earn a certain amount of revenue, marked as S per unit. In this way, SQ represents the total revenue. The second term of the above expression represents the total holding cost during the hedged lead-time period for any l. The third term is the tardiness penalty for the working hour loss due to late delivery. Given the assumption that none order will be cancelled, this penalty money is involved as an effective way to prevent and punish late delivery.

As for prefab manufacturer, he receives the order from the construction site manager. The order information specifies the form of the prefabs, the quantity as well as the due date. The overwork cost is increasing with the lead-time hedging amount and thus its profit will decrease with l. The profit function for the prefab manufacturing department is shown below:

$$\Pi_{PM}^{UD}(l) = PQ - CQl. \quad (2)$$

If we substitute the on-time delivery probability distribution function into (1) and simplify the equation. The profit functions of those two parties can be rewritten as follow:

$$\Pi_{OS}^{UD}(l) = SQ - PQ - HQla - \frac{HQae^{-\lambda l}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l}}{\lambda}, \quad (3)$$

$$\Pi_{PM}^{UD}(l) = PQ - CQl. \quad (4)$$

Proposition 1. *In order to ensure that the lead-time hedging strategy introduced by the construction site department is meaningful, the relationship between H and T satisfies the following equation:*

$$H \le T\frac{1-e^{-\lambda d}}{\lambda d + e^{-\lambda d} - 1}. \quad (5)$$

Under this condition, it is more profitable for the construction site department to quote a positive lead-time hedging value for each order.

Proof. For a proof of this proposition and all subsequent proofs, see Appendix I.

Proposition 2. *The profit function for the construction site department is an increasing concave function of the lead-time hedging amount l and the optimal l is characterized by the following equation:*

$$l^{UD} = -\frac{1}{\lambda}ln\frac{H}{H+T}. \quad (6)$$

Proposition 3. *The prefab manufacturing department and construction site department's profit under the unilateral decision model for each order are characterized as follows:*

$$\Pi_{PM}^{UD}(l^{UD}) = PQ - CQl^{UD}. \quad (7)$$

$$= PQ + CQ\frac{1}{\lambda}ln\frac{H}{H+T},$$

$$\Pi_{OS}^{UD}(l^{UD}) = SQ - PQ - HQl^{UD}a - \frac{HQae^{-\lambda l^{UD}}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l^{UD}}}{\lambda} \quad (8)$$

$$= SQ - PQ + HQa\frac{1}{\lambda}ln\frac{H}{H+T} - \frac{H^2Qa}{\lambda(H+T)} + \frac{HQa}{\lambda} - \frac{aHQT}{\lambda(H+T)}.$$

5. GLOBAL OPTIAML MODEL

In the traditional model, the construction site department is powerful enough to scarify the prefab manufacturing department's profit to benefit itself. However, in the global optimal model, the lead-time hedging amount is chosen to maximize the entire supply chain's profit. Specifically, the entire supply chain has been treated as a centralized system and the total profit includes the prefab manufacturing department and construction site department. Thus, the total profit is expressed as follow:

$$\Pi^{GO}(l) = \Pi_{PM}^{GO}(l) + \Pi_{OS}^{GO}(l)$$

$$= SQ - CQl - HQ\int_0^l (l-t)dP(t) - TQ\int_l^\infty (t-l)dP(t)$$

$$= SQ - CQl - HQla - \frac{HQae^{-\lambda l}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l}}{\lambda}. \quad (9)$$

Proposition 4. *The total profit is a concave function of the lead-time hedging amount l and the optimal l is characterized by the following equation:*

$$l^{GO} = -\frac{1}{\lambda}ln\frac{H+\frac{C}{a}}{H+T}. \quad (10)$$

6. STACKELBERG GAME MODEL WITH COST SHARING COORDINATION

6.1. Stackelberg game model

In this section, a coordination scheme is studied. Each department is able to take actions to maximize its own profit. Specifically, an additional money will be charged by the prefab manufacturing department to mitigate its extra investigation for overwork within a shorter lead-time. This additional money w is increasing with the lead-time hedging amount l. A Stackelberg game is introduced in this part.

In the game, the prefab manufacturing department acts as the game leader who decides the additional money w for each order. The prefab manufacturer chooses the additional money while taking the reaction of construction site department into consideration on the first stage. Later on, the construction site department determines the lead-time hedging amount for a given w. The profit functions for each department are shown as follows:

$$\Pi_{PM}^{SG}(l,w) = PQ - CQl + wQP(l),$$

$$\Pi_{OS}^{SG}(l,w) = SQ - PQ - HQ\int_0^l (l-t)dP(t) - TQ\int_l^\infty (t-l)dP(t) - wQP(l).$$

The additional part $wQP(l)$ represents the expected revenue for each order. While $P(l)$ represents the possibility that the prefab manufacturing department can fulfil an order on time, it can also be viewed as the probability that the prefab manufacturing department can receive

the additional money from the construction site department. The rest parts of the function are similar with function (1) and (2).
If we substitute the on-time delivery probability distribution function into above profit functions, the objective functions of those two parties can be rewritten as follows:

$$\Pi_{PM}^{SG}(l,w) = PQ - CQl + wQ\left(1 - ae^{-\lambda l}\right), \tag{11}$$

$$\Pi_{OS}^{SG}(l,w) = SQ - PQ - HQla - \frac{HQae^{-\lambda l}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l}}{\lambda} - wQ\left(1 - ae^{-\lambda l}\right). \tag{12}$$

Proposition 5. *Under the Stackelberg game model, the optimal strategy for the prefab manufacturing department and the construction site department are decided by the Stackelberg equilibrium, as follows:*

$$w^{SG} = \frac{2H+2T+C-\sqrt{C^2+4(H+T)Ha}}{2\lambda}, \tag{13}$$

$$l^{SG} = -\frac{1}{\lambda} ln \frac{H}{H+T-\lambda w} \quad \left(w \leq \frac{T}{\lambda}\right).$$

If $> \frac{T}{\lambda}$, then $l^{SG} = 0$ and $w = 0$. (14)

6.2. Cost sharing coordination

In this part, we compare the profit of the construction site department under the unilateral decision model, global optimal model and the Stackelberg game model. Actually, the substantial propose of the construction site department to adopt lead-time hedging strategy is to increase its profit by reducing late delivery. Although the prefab manufacturing department and the construction site department working cooperatively, it is not to say that they are integrated in a firm. In this way, their revenue should be calculated respectively. In section 7, we can see that the total profit of the entire supply chain is very close to the global optimal model. However, the profit of the construction site department is lower than the global optimal one. In this way, even on-time delivery probability can be enhanced, the construction site department's profit is relatively lower. Intuitively, under such condition, the construction site department will not to adopt lead-time hedging strategy for it's profitless.

To cope with this profit decreasing, we discuss a cost sharing coordination contract to compensate the construction site department's loss under this game model. We introduce the cost sharing rate β ($0 \leq \beta \leq 1$) in this section. The fraction $(1-\beta)[TQ\int_l^{\infty}(t-l)dP(t) + wQP(l)]$ will be shared by the prefab manufacturing department, and the rest $\beta[TQ\int_l^{\infty}(t-l)dP(t) + wQP(l)]$ reserved to the construction site department.
The profit of construction site department under the Stackelberg game model should larger than its profit under the global optimal model. Only in this way, will the construction site department willing to take part in to the coordination contract. Also, the profit of the prefab manufacturing department under this cost sharing contract is also larger than its profit under unilateral decision model. Otherwise this cost sharing coordination contract will not be accepted by the prefab manufacturing department. Combining the above descriptions, we got the following proposition.

Proposition 6. *Under the Stackelberg game theory with cost sharing coordination contract, the sharing rate* β *should satisfies the following equation:*

$$\frac{\frac{CQ}{\lambda}\ln\frac{H+T-\lambda w}{H+T}+\frac{TQHa}{\lambda(H+T-\lambda w)}}{\frac{TQHa}{\lambda(H+T-\lambda w)}+wQ(1-\frac{Ha}{H+T-\lambda w})} \leq \beta \ \leq \frac{-\frac{HQa}{\lambda}\ln\frac{\left(H+\frac{C}{a}\right)(H+T-\lambda w)}{(H+T)H}+\frac{HQa}{\lambda}\left(\frac{T-\lambda w}{H+T-\lambda w}\right)+\frac{CQ}{\lambda}}{\frac{TQHa}{\lambda(H+T-\lambda w)}+wQ(1-\frac{Ha}{H+T-\lambda w})}, (0 \leq \beta \leq 1).$$

7. COMPARATIVE ANALYSIS AND NUMERICAL STUDIES

Solutions in proposition 2,3,4 and 5 provide the basis for the unilateral decision model, global optimal model and the Stackelberg game model. In this section, we compare the performances of these three models. In addition, we also compare their performances with a cost sharing contract under the Stackelberg game model. Later on, numerical studies are also provided to show some results and point out more insights.

We examine how the different models influence the behaviours of the prefab manufacturer and the construction site manager. Specifically, how are the lead-time hedging amount influenced by different models? How are the prefab manufacturing department's profit and the construction site department's profit influenced by these models? We also discuss the global profit of the entire supply chain. In addition, we compare the performances of the prefab manufacturing and construction site department under the Stackelberg model with and without cost sharing contract. Does the Stackelberg game model with cost sharing contract outperforms the above mentioned three models?

7.1. Comparison analysis

In this section, we compare the performances of the unilateral decision model, global optimal model and the Stackelberg game model. Three findings are listed below.

Result 1. *The lead-time hedging amount follows:* $l^{SG} < l^{GO} < l^{UD}$.

Result 2. *The prefab manufacturing's profit follows:* $\Pi_{PM}^{SG} > \Pi_{PM}^{GO} > \Pi_{PM}^{UD}$.

Result 3. *The construction site department's profit follows:* $\Pi_{OS}^{UD} > \Pi_{OS}^{GO} > \Pi_{OS}^{SG}$.

From the demonstration part of proposition 6 we have already proved that $\Pi_{OS}^{UD} > \Pi_{OS}^{GO} > \Pi_{OS}^{SG}$ and here is omitted.
From the results 1 to 3, we can see that the introduced Stackelberg game model with additional money reduces the lead-time hedging amount. The profit of prefab manufacturing department is also enhanced. The saved capacity of prefab manufacturing department can be used to process other orders. However, the construction site department's profit under Stackelberg game model is the lowest one among these three models. In the following part, we will compare the total profit which includes the prefab manufacturing department and the construction site department. Also, we will show the performances of the cost sharing contract under Stackelberg game model. Specifically, we will compare the profit of prefab manufacturing department and construction site department under Stackelberg game model with and without cost sharing contract.

7.2. Numerical studies of total profit and the performance of cost sharing contract

In this subsection, we present numerical studies to compare the total profit of the prefab supply chain. Also we compare the individual department's profit under Stackelberg game model with and without cost sharing contract respectively. The gaps of lead-time hedging amount under different model is also studied. The numerical studies are performed based on the sensitivity analysis of three parameters of these models: the fixed revenue on-site, the holding cost during the hedged lead-time per unit per time and the tardiness cost. Since these three parameters are decided exogenous, it is necessary for us to see how the decision variables and profit influenced by them. In all the examples, we initially set S=750, H=30, T=300, α=0.5, $\lambda = 1$, Q=1, P=360 and C=120.

The sensitivity analysis illustrates the effect of parameter S, H and T on the lead-time hedging amount l and the total profit. In addition, it shows the differences of each department's profit under Stackelberg game model with and without cost sharing contract. For table 1,2 and 3 see appendix II. The results are also graphically displayed in Figure 2 to 7.

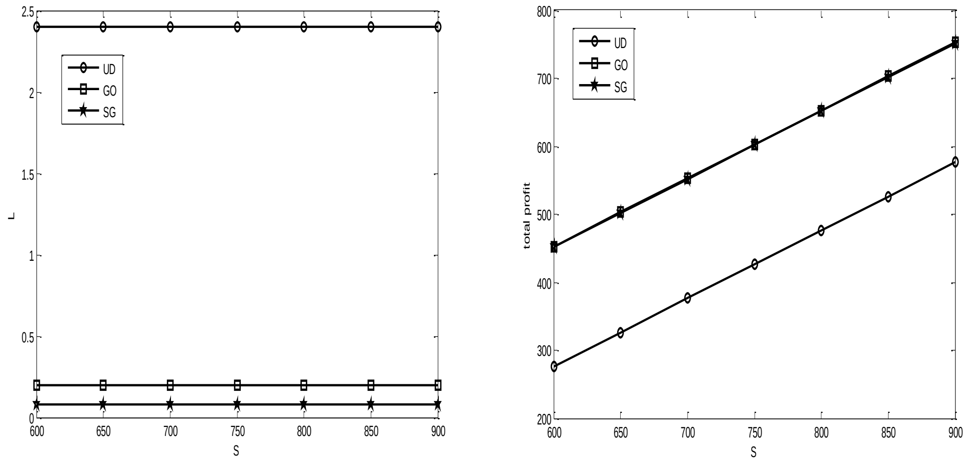

Figure 2. The effect of S on l and Π

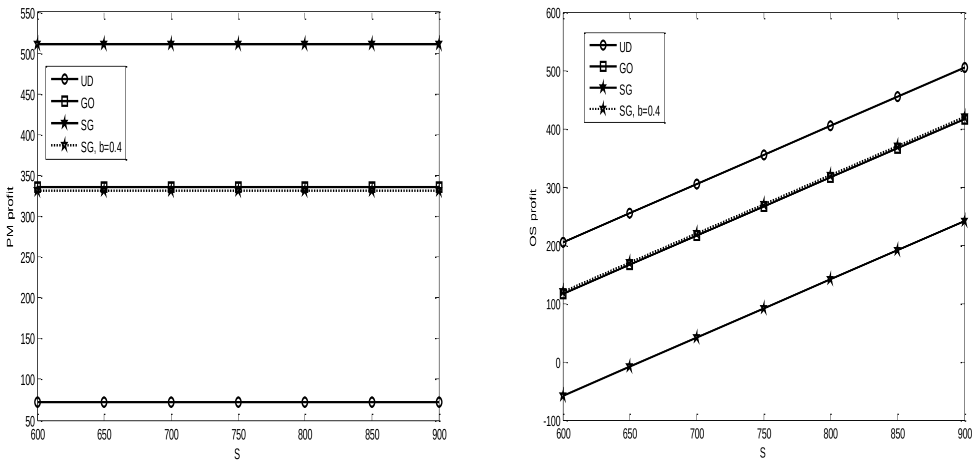

Figure 3. The effect of S and $\beta = 0.4$ on Π_{PM} and Π_{OS}

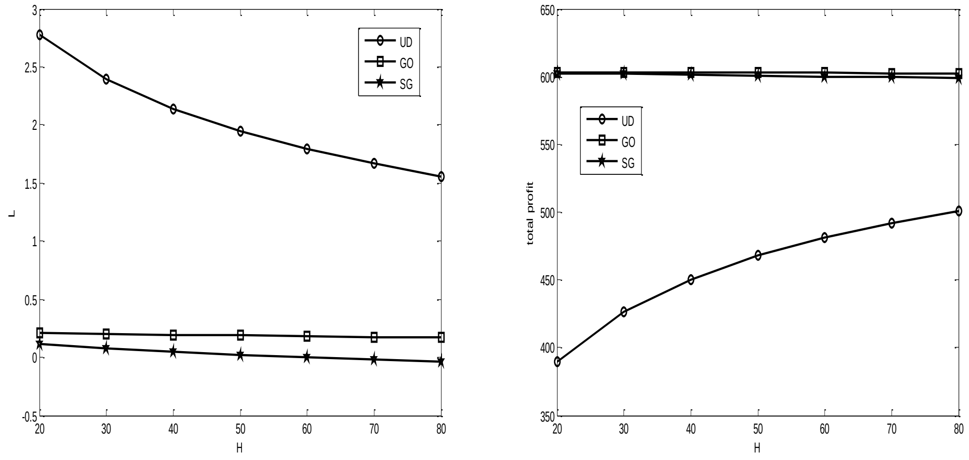

Figure 4. The effect of H on l and Π

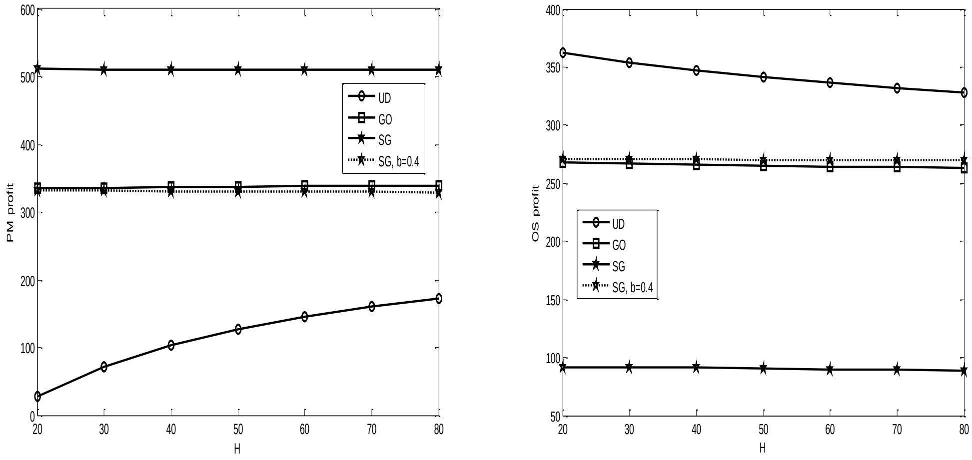

Figure 5. The effect of H and $\beta = 0.4$ on Π_{PM} and Π_{OS}

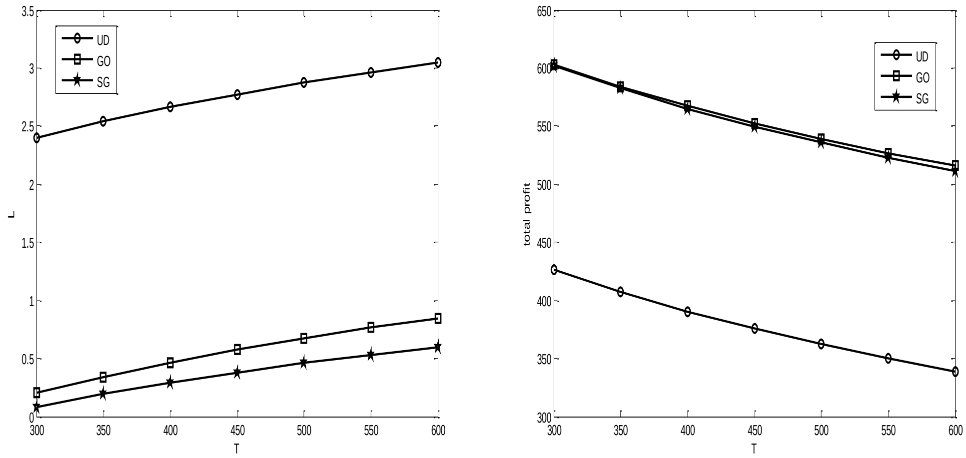

Figure 6. The effect of T on l and Π

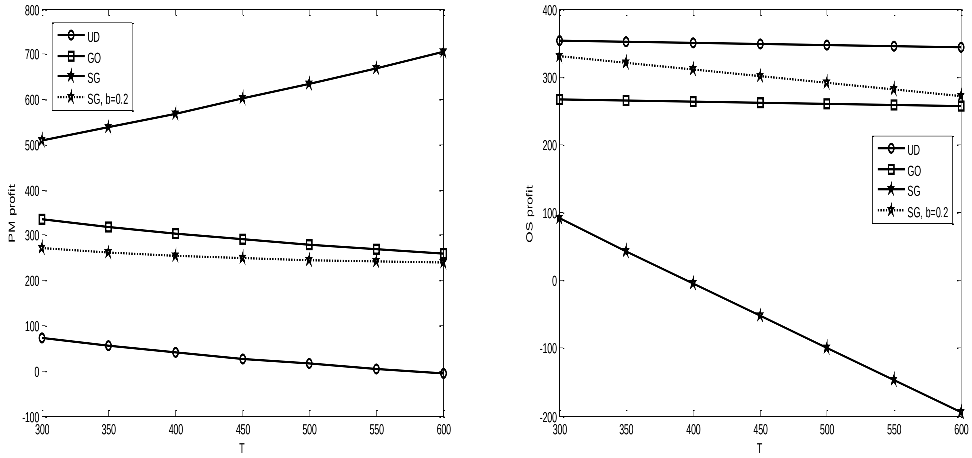

Figure 7. The effect of T and $\beta = 0.2$ on Π_{PM} and Π_{OS}

As we can see from the figures, the lead-time hedging amount obtained from the Stackelberg game model is the smallest one, followed by that obtained by the global optimal model and the unilateral decision model. This matches our comparison result of the lead-time hedging amount described in the Section 7.1. It confirms that the proposed Stackelberg game model can successfully reduce the lead-time hedging amount.

From the left side of the figure 4 and 6, it can be observed that l is increasing with T and decreasing with H. Since if T is higher, a longer l should be chosen to avoid expensive penalty. However, from the left side of figure 2 we can see that l is not influenced by the fixed revenue. Since in the assumption part, we assumes that the order will not be cancelled for any late delivery (the late delivery is hedged by tardiness penalty) which means that the construction site department will definitely earn this part of money once they finished the corresponding task. In this way, even this parameter influence the total profit of the supply chain as the right side of figure 2 shows, it does not influence the lead-time decision.

Other insights form the tables and the figures are shown below. Firstly, the entire profit of the prefab supply chain under Stackelberg game model is similar with it under the global optimal model. The total profit gap between these two models is very small. To this end, we can see that the Stackelberg game model enhances the efficiency of this supply chain. Moreover from figure 3, 5 and 7, we can observe that the profit of the prefab manufacturer and the construction site department is similarly with its profit under global optimal model after the cost sharing coordination contract get involved. Actually, if only the Stackelberg game model works, even though the profit of entire supply chain will increase, as compared with the unilateral decision model, it sacrifices the interests of the construction site department. In this way, a cost sharing contract which attracts the construction site department to take an active part in the Stackelberg game is introduced to balance the profit change of each department. The cost sharing rate β follows the proposition 6, however its actual value should be negotiated by the prefab manufacturer and the construction site manager.

8. CONCLUSIONS

In this paper, we put forward a coordination scheme for the prefab manufacturing department and the construction site department to solve the conflict caused by the lead-time hedging strategy. In our research, an additional price was involved and a Stackelberg game model was introduced. In this model, the prefab manufacturer serves as a leader who decides the addition price w, and construction site department acts as a follower who determines the lead-time hedging amount. From the comparative analysis and numerical studies we can see that the proposed model reduces the lead-time hedging amount and enhance the profit for entire supply chain, as compared with the unilateral decision model. However, even the performances of this strategy are when compared with the unilateral decision model and the global optimal model, it sacrifices the benefit of the construction site department. In this way, a cost sharing contract was introduced to balance the benefit for both departments. Some fractions the additional cost and tardiness cost will be shared by the prefab manufacturing department. Further comparisons show that the coordination model with cost sharing contract performs well to benefit both parts.

In the future research, we will extend our research scope and consider more settings. Specifically, we will consider the uncertainties of the logistic provider. We will also consider to divide the lead-time hedging amount into two parts which will be shouldered by the prefab manufacturer and logistic provider respectively. Besides these, we will also consider the relationship between order quantity and price. These pursuits are lift for further research.

ACKNOWLEDGEMENTS

Authors are grateful to Zhejiang Provincial, Hangzhou Municipal, Lin'an City governments, as well as ITF Innovation and Technology Support Programme (ITP/045/13LP). This project is supported by National Natural Science Foundation of China (Grant No. 51305376) and The University of Hong Kong Small project Fund (201209176052).

APPENDIX I. MATHEMATICAL PROOFS

Proof of proposition 1. The main thrust of involving the lead-time hedging strategy is to increase on-time delivery probability of prefabs as well as enhance the profit of construction site. In this way, $\Pi_{OS}^{UD}(l) \geq \Pi_{OS}^{UD}(0)$ should always hold. That is:

$\Pi_{OS}^{UD}(l) = SQ - PQ - HQla - \frac{HQae^{-\lambda l}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l}}{\lambda} \geq \Pi_{OS}^{UD}(0) = SQ - PQ - \frac{TQa}{\lambda}$.

Then, we get:

$$H \leq T\frac{1 - e^{-\lambda l}}{\lambda l + e^{-\lambda l} - 1}.$$

If $x = \lambda l$, then $0 < x < \lambda d$.For math convenience, we let $f(x) = \frac{1-e^{-x}}{x+e^{-x}-1}$. We can easily get $'(x) = \frac{xe^{-x}+e^{-x}-1}{(x+e^{-x}-1)^2}$.

Let $h(x) = xe^{-x} + e^{-x} - 1$ and it first derivative is:

$h'(x) = -xe^{-x} < 0.$

So, $h(x)$ is decreasing with x and $h(0) = 0$. It means that $f(x)$ is decreasing with x. The minimum $f(x)$ occurs when $x = \lambda l$. Thus, we have:

$H \leq T\frac{1-e^{-\lambda d}}{\lambda d+e^{-\lambda d}-1}$.

Proof of proposition 2. In the unilateral decision model, the objective is to find an *l* that maximizes the construction site department's profit. It is easy to see that $\Pi_{OS}^{UD}(l)$ is a continuous function. Its first derivative is:

$\frac{\partial \Pi_{OS}^{UD}(l)}{\partial l} = -HQa + HQae^{-\lambda l} + TQae^{-\lambda l} > 0$

and the second derivative is:

$\frac{\partial^2 \Pi_{OS}^{UD}(l)}{\partial l^2} = -HQa\lambda e^{-\lambda l} - TQa\lambda e^{-\lambda l} \leq 0.$

In this way, we have that $\Pi_{OS}^{UD}(l)$ is an increasing and concave function.

Since *H*, *T* >0, thus, *H*+*T* >*H* which ensures that *l* is always nonnegative. There exists an *l* to make the first derivative equals to 0, and this value is the optimal value for the construction site department to maximize its own profit. We have

$\frac{\partial \Pi_{OS}^{UD}(l)}{\partial l} = -HQa + HQae^{-\lambda l} + TQae^{-\lambda l} = 0.$

Then, we get:

$$l^{UD} = -\frac{1}{\lambda} ln\frac{H}{H + T}.$$

Proof of proposition 3. Substituting the optimal l^{UD} under unilateral decision model into $\Pi_{PM}^{UD}(l)$ and $\Pi_{OS}^{UD}(l)$, the profits function for each department are obtained. Since $H \leq T\frac{1-e^{-\lambda d}}{\lambda d+e^{-\lambda d}-1}$, construction site department always prefers to involve a positive lead-time hedging amount, for it is more profitable.

Proof of proposition 4. The first derivative of $\Pi^{GO}(l)$ is:

$\frac{\partial \Pi^{GO}(l)}{\partial l} = -CQ - HQa + HQae^{-\lambda l} + TQae^{-\lambda l}$

and the second derivative is:

$\frac{\partial^2 \Pi^{GO}(l)}{\partial l^2} = -HQa\lambda e^{-\lambda l} - TQa\lambda e^{-\lambda l} \leq 0$

Thus, $\Pi^{GO}(l)$ is a concave function and the optimal value l under this circumstance is obtained by $\frac{\partial \Pi^{GO}(l)}{\partial l} = 0$, then, we have:

$$l^{GO} = -\frac{1}{\lambda} ln \frac{H + \frac{C}{a}}{H + T}.$$

Proof of proposition 5. The first derivation of $\Pi_{OS}^{SG}(l, w)$ is:

$$\frac{\partial \Pi_{OS}^{SG}(l,w)}{\partial l} = -HQa + HQae^{-\lambda l} + TQae^{-\lambda l} - wa\lambda Qe^{-\lambda l}. \qquad (15)$$

The second derivative is:

$$\frac{\partial^2 \Pi_{OS}^{SG}(l,w)}{\partial l^2} = -Qa\lambda e^{-\lambda l}(H + T - \lambda w). \qquad (16)$$

When $w \leq \frac{T}{\lambda}$ we have $\frac{\partial^2 \Pi_{OS}^{SG}(l,w)}{\partial l^2} \leq 0$. Thus $\Pi_{OS}^{SG}(l, w)$ is a concave function. The optimal l^{SG} is obtained when the first derivative equals 0. In this way, we have:

$$l^{SG} = -\frac{1}{\lambda} ln \frac{H}{H+T-\lambda w}.$$

If $w > \frac{T}{\lambda}$, we have

$$\frac{\partial \Pi_{OS}^{SG}(l,w)}{\partial l} = -HQa + HQae^{-\lambda l} + TQae^{-\lambda l} - wa\lambda Qe^{-\lambda l} < 0.$$

Since $l \geq 0$, the optimal lead-time hedging amount should be zero.

Substituting the optimal l^{SG} into the prefab manufacturing department's profit function, its profit function can be rewritten as:

$$\Pi_{PM}^{SG}(l, w) = PQ + CQ\frac{1}{\lambda} ln \frac{H}{H+T-\lambda w} + wQ(1 - a\frac{H}{H+T-\lambda w})$$
$$= PQ + CQ\frac{1}{\lambda}[ln H - \ln(H + T - \lambda w)] + wQ\left(1 - a\frac{H}{H+T-\lambda w}\right). \qquad (17)$$

The first derivative is:

$$\frac{\partial \Pi_{PM}^{SG}(l,w)}{\partial w} = CQ\frac{H}{H+T-\lambda w} + Q\left(1 - a\frac{H}{H+T-\lambda w}\right) - wa\lambda HQ\frac{1}{(H+T-\lambda w)^2}$$
$$= Q[1 - \frac{1}{H+T-\lambda w}\left(Ha - C + \frac{wa\lambda H}{H+T-\lambda w}\right)].$$

Computing the first derivative $\frac{\partial \Pi_{PM}^{SG}(l,w)}{\partial w} = 0$, we get the extreme point

$$w^{SG} = \frac{2H+2T+C\pm\sqrt{C^2+4(H+T)Ha}}{2\lambda},$$

Since, $H + T - \lambda w \geq 0$, we have,

$$w^{SG} = \frac{2H+2T+C-\sqrt{C^2+4(H+T)Ha}}{2\lambda}.$$

In the following part, we show that the extreme point w^{SG} is the maximum value point. We let w^* satisfy:

$$1 - \frac{1}{H+T-\lambda w^*}\left(Ha - C + \frac{w^* a\lambda H}{H+T-\lambda w^*}\right) = 0. \qquad (18)$$

Case 1: When $w < w^*$, we have

$\frac{1}{H+T-\lambda w} < \frac{1}{H+T-\lambda w^*}$ and $\frac{wa\lambda H}{H+T-\lambda w} < \frac{w^* a\lambda H}{H+T-\lambda w^*}$.

If $Ha - C + \frac{wa\lambda H}{H+T-\lambda w} > 0$, then we have:

$$1 - \frac{1}{H+T-\lambda w}\left(Ha - C + \frac{wa\lambda H}{H+T-\lambda w}\right) > 1 - \frac{1}{H+T-\lambda w*}\left(Ha - C + \frac{w^* a\lambda H}{H+T-\lambda w^*}\right) = 0.$$

If $Ha - C + \frac{wa\lambda H}{H+T-\lambda w} \leq 0$, then $1 - \frac{1}{H+T-\lambda w}\left(Ha - C + \frac{wa\lambda H}{H+T-\lambda w}\right) > 0$.

In this way, we can see that $\Pi_{PM}^{SG}(l, w)$ is increasing with w, when $w < w*$.

Case 2: When $w > w^*$, we have

$\frac{1}{H+T-\lambda w} > \frac{1}{H+T-\lambda w^*}$ and $\frac{wa\lambda H}{H+T-\lambda w} > \frac{w^* a\lambda H}{H+T-\lambda w^*}$.
Since $1-\frac{1}{H+T-\lambda w^*}\left(Ha-C+\frac{w^*\, a\lambda H}{H+T-\lambda w^*}\right)=0$, and $H+T-\lambda w^* > 0$. We have
$Ha-C+\frac{w^*\, a\lambda H}{H+T-\lambda w^*}>0$, and thus
$Ha-C+\frac{wa\lambda H}{H+T-\lambda w} > 0$.
$1-\frac{1}{H+T-\lambda w}\left(Ha-C+\frac{wa\lambda H}{H+T-\lambda w}\right) < 1-\frac{1}{H+T-\lambda w^*}\left(Ha-C+\frac{w^* a\lambda H}{H+T-\lambda w^*}\right) = 0$.
In this way, we can see that $\Pi_{PM}^{SG}(l,w)$ is decreasing with w, when $w > w^*$.
Therefore, the extreme point w^{SG} is the maximum value point and $\Pi_{PM}^{SG}(l,w)$ is quasi-concave.
Since $\Pi_{OS}^{SG}(l,w)$ is concave and $\Pi_{PM}^{SG}(l,w)$ is quasi-concave, the Stackelberg equilibrium exists. If $w > \frac{T}{\lambda}$ there is no need to involve lead-time hedging and thus $l=0$ and $w=0$, and thus, the profit function can be obtained directly.

Proof of proposition 6. Substituting the l^{UD}, l^{GO} and l^{SG} into the construction site department's profit function respectively, we have:

$$\Pi_{OS}^{UD}(l^{UD}) = SQ - PQ - HQl^{UD}a - \frac{HQae^{-\lambda l^{UD}}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l^{UD}}}{\lambda},$$

$$\Pi_{OS}^{GO}(l^{GO}) = SQ - PQ - HQl^{GO}a - \frac{HQae^{-\lambda l^{GO}}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l^{GO}}}{\lambda}$$

$$= SQ - PQ + HQa\frac{1}{\lambda}\ln\frac{H+\frac{C}{a}}{H+T} - \frac{HQa(H+\frac{C}{a})}{\lambda(H+T)} + \frac{HQa}{\lambda} - \frac{aQT(H+\frac{C}{a})}{\lambda(H+T)},$$

$$\Pi_{OS}^{SG}(l^{SG},w)$$

$$= SQ - PQ - HQl^{SG}a - \frac{HQae^{-\lambda l^{SG}}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l^{SG}}}{\lambda} - wQ\left(1-\frac{Ha}{H+T-\lambda w}\right)$$

$$= SQ - PQ + HQa\frac{1}{\lambda}\ln\frac{H}{H+T-\lambda w} - \frac{H^2Qa}{\lambda(H+T-\lambda w)} + \frac{HQa}{\lambda} - \frac{aQTH}{\lambda(H+T-\lambda w)} - wQ\left(1-\frac{Ha}{H+T-\lambda w}\right).$$

To compare $\Pi_{OS}^{UD}(l^{UD})$, $\Pi_{OS}^{GO}(l^{GO})$ and $\Pi_{OS}^{SG}(l^{SG})$, from the above expression, we should firstly compare

$$-HQl^{UD}a - \frac{HQae^{-\lambda l^{UD}}}{\lambda} - \frac{TQae^{-\lambda l^{UD}}}{\lambda},$$

$$-HQl^{GO}a - \frac{HQae^{-\lambda l^{GO}}}{\lambda} - \frac{TQae^{-\lambda l^{GO}}}{\lambda},$$

and

$$-HQl^{SG}a - \frac{HQae^{-\lambda l^{SG}}}{\lambda} - \frac{TQae^{-\lambda l^{SG}}}{\lambda}.$$

For math convenience, we let $g(l) = -HQla - \frac{HQae^{-\lambda l}}{\lambda} - \frac{TQae^{-\lambda l}}{\lambda}$. The first derivative of $g(l)$ is:

$$g'(l) = -HQa(1-e^{-\lambda l}) + TQae^{-\lambda l}.$$

From the above equation we have: $g'(l)$ is nonnegative, when $e^{-\lambda l} \geq \frac{H}{H+T}$.

$$\text{Since, } e^{-\lambda l^{SG}} = \frac{H}{H+T-\lambda w} \geq e^{-\lambda l^{GO}} = \frac{H+\frac{C}{a}}{H+T} \geq e^{-\lambda l^{UD}} = \frac{H}{H+T}. \quad (19)$$

We can see that $e^{-\lambda l} \geq \frac{H}{H+T}$ is always hold in these models and in this way, $g(l)$ is increasing with l under such condition.
From proposition 2, 4 and 5, we have $l^{SG} < l^{GO} < l^{UD}$, the demonstration detail can be seen in the Section 7. Result 1 and here is omitted. Thus, $g(l^{SG}) < g(l^{GO}) < g(l^{UD})$. Consequently, we have $\Pi_{OS}^{UD}(l^{UD}) > \Pi_{OS}^{GO}(l^{GO}) > \Pi_{OS}^{SG}(l^{SG}, w^{SG})$.

In order to attract construction site department involved in the Stackelberg game model, a positive β should be involved to compensate its overwork investigation. That is:

$$\Pi_{OS}^{SG}(l^{SG}, w^{SG}, \beta)$$
$$= SQ - PQ - HQl^{SG}a - \frac{HQae^{-\lambda l^{SG}}}{\lambda} + \frac{HQa}{\lambda} - \beta[\frac{TQae^{-\lambda l^{SG}}}{\lambda} + wQ(1 - \frac{Ha}{H+T-\lambda w})]$$
$$\geq \Pi_{OS}^{GO}(l^{GO}) = SQ - PQ - HQl^{GO}a - \frac{HQae^{-\lambda l^{GO}}}{\lambda} + \frac{HQa}{\lambda} - \frac{TQae^{-\lambda l^{GO}}}{\lambda} \ (0 \leq \beta \leq 1). \quad (20)$$

Furthermore, the cost sharing rate β cannot as small as willingly. It should also ensure that the prefab manufacturing department is profitable. Substituting l^{SG}, l^{GO} and l^{UD} to the prefab manufacturing department's profit function, we have:

$\Pi_{PM}^{SG} > \Pi_{PM}^{GO} > \Pi_{PM}^{UD}$, the demonstration detail can be seen in the Section 7. Result 2 and here is omitted. In order to guarantee that the prefab manufacturing department is also profitable, the involved β should satisfies $\Pi_{PM}^{SG}(l^{SG}, w^{SG}, \beta) \geq \Pi_{PM}^{UD}$, that is:

$$\Pi_{PM}^{SG}(l^{SG}, w^{SG}, \beta) = PQ - CQl^{SG} + \beta wQP(l^{SG}) - (1-\beta)TQ\int_{l^{SG}}^{\infty}(t - l^{SG})dP(t)$$
$$\geq \Pi_{PM}^{UD}(l^{UD}) = PQ - CQl^{UD} \ \ (0 \leq \beta \leq 1). \quad (21)$$

Substituting $l^{SG} = -\frac{1}{\lambda}ln\frac{H}{H+T-\lambda w}$, $l^{GO} = -\frac{1}{\lambda}ln\frac{H+\frac{C}{a}}{H+T}$, $l^{UD} = -\frac{1}{\lambda}ln\frac{H}{H+T}$ into (20) and (21).

Thus, we have:

$$\frac{\frac{CQ}{\lambda}\ln\frac{H+T-\lambda w}{H+T}+\frac{TQHa}{\lambda(H+T-\lambda w)}}{\frac{TQHa}{\lambda(H+T-\lambda w)}+wQ(1-\frac{Ha}{H+T-\lambda w})} \leq \beta \leq \frac{-\frac{HQa}{\lambda}\ln\frac{\left(H+\frac{C}{a}\right)(H+T-\lambda w)}{(H+T)H}+\frac{HQa}{\lambda}\left(\frac{T-\lambda w}{H+T-\lambda w}\right)+\frac{CQ}{\lambda}}{\frac{TQHa}{\lambda(H+T-\lambda w)}+wQ(1-\frac{Ha}{H+T-\lambda w})} \ \ (0 \leq \beta \leq 1)$$

Where *w* satisfies equation (13).

Proof of result 1. Previously, we have:

$l^{SG} = -\frac{1}{\lambda}ln\frac{H}{H+T-\lambda w}$, $l^{GO} = -\frac{1}{\lambda}ln\frac{H+\frac{C}{a}}{H+T}$, $l^{UD} = -\frac{1}{\lambda}ln\frac{H}{H+T}$.

If $w \leq \frac{T}{\lambda}$, we have $\frac{H}{H+T-\lambda w} > \frac{H}{H+T}$. Thus, $l^{SG} < l^{UD}$.

Since, $\frac{H+\frac{C}{a}}{H+T} > \frac{H}{H+T}$, then we have $l^{GO} < l^{UD}$.

From equation (18) we have:

$1 - \frac{1}{H+T-\lambda w^*}\left(Ha - C + \frac{w^* a\lambda H}{H+T-\lambda w^*}\right) = 0$.

Since $0 < \frac{H}{H+T-\lambda w^*} < 1$, and a>0, thus, $0 < \frac{Ha}{H+T-\lambda w^*} < 1$.

In this way, $\frac{1}{H+T-\lambda w^*}\left(\frac{w^* a\lambda H}{H+T-\lambda w^*} - C\right) = 1 - \frac{Ha}{H+T-\lambda w^*} > 0$.

In order to compare l^{SG} and l^{GO}, we only need to compare $\frac{H}{H+T-\lambda w}$ and $\frac{H+\frac{C}{a}}{H+T}$.

Since, $\frac{H}{H+T-\lambda w} - \frac{H+\frac{C}{a}}{H+T} = \frac{H(aH+aT)-(H+T-\lambda w)(Ha+C)}{(H+T-\lambda w)(aH+aT)} = \frac{1}{aH+aT}\left(\frac{wa\lambda H}{H+T-\lambda w} - C\right) > 0$.

We have, $l^{SG} < l^{GO}$.

Thus, we have, $l^{SG} < l^{GO} < l^{UD}$.

Proof of result 2. From the proposition 2,4,5. We have:

$\Pi_{PM}^{UD}(l) = PQ - CQl^{UD}$,

$\Pi_{PM}^{GO}(l) = PQ - CQl^{GO}$,

$\Pi_{PM}^{SG}(l,w) = PQ - CQl^{SG} + wQP(l^{SG})$.

From result 1 we have $l^{SG} < l^{GO} < l^{UD}$.

Since, $wQP(l^{SG}) \geq 0$, thus we have $\Pi_{PM}^{SG} > \Pi_{PM}^{GO} > \Pi_{PM}^{UD}$.

APPENDIX II. TABLES FOR SENSITIVITY ANALYSIS

Table 1. Sensitivity analysis of three models with respect to *S*

S	600	650	700	750	800	850	900
l^{UD}	2.40	2.40	2.40	2.40	2.40	2.40	2.40
Π^{UD}	276.28	326.28	376.28	426.28	476.28	526.28	576.28
l^{GO}	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Π^{GO}	452.91	502.91	552.91	602.91	652.91	702.91	751.91
l^{SG}	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Π^{SG}	451.87	501.87	551.87	601.87	651.87	701.87	751.87
Π^{UD}_{PM}	72.25	72.25	72.25	72.25	72.25	72.25	72.25
Π^{GO}_{PM}	335.92	335.92	335.92	335.92	335.92	335.92	335.92
Π^{SG}_{PM}	510.59	510.59	510.59	510.59	510.59	510.59	510.59
$\Pi^{SG,\beta=0.4}_{PM}$	331.38	331.38	331.38	331.38	331.38	331.38	331.38
Π^{UD}_{OS}	204.03	254.03	304.03	354.03	404.03	454.03	504.03
Π^{GO}_{OS}	116.99	166.99	216.99	266.99	316.99	366.99	416.99
Π^{SG}_{OS}	-58.72	-8.72	41.28	91.28	141.28	191.28	241.28
$\Pi^{SG,\beta=0.4}_{OS}$	120.49	170.49	220.49	270.49	320.49	370.49	420.49

Table 2. Sensitivity analysis of three models with respect to *H*

H	20	30	40	50	60	70	80
l^{UD}	2.77	2.40	2.14	1.95	1.79	1.67	1.56
Π^{UD}	389.56	426.28	450.39	467.84	481.24	491.92	500.70
l^{GO}	0.21	0.20	0.19	0.19	0.18	0.18	0.17
Π^{GO}	603.01	602.91	602.82	602.73	602.65	602.58	602.50
l^{SG}	0.12	0.08	0.04	0.02	0.00	-0.02	-0.04
Π^{SG}	602.45	602.87	601.25	600.63	600.00	599.38	598.77
Π^{UD}_{PM}	27.29	72.25	103.19	126.49	144.99	160.20	173.02
Π^{GO}_{PM}	335.08	335.92	336.70	337.43	338.12	338.77	339.38
Π^{SG}_{PM}	511.14	510.59	510.24	510.06	510.00	510.05	510.18
$\Pi^{SG,\beta=0.4}_{PM}$	331.96	331.38	330.86	330.40	330.00	329.65	329.35
Π^{UD}_{OS}	362.27	354.03	347.20	341.35	336.25	331.72	327.67
Π^{GO}_{OS}	267.92	266.99	266.12	265.30	264.53	263.81	263.13
Π^{SG}_{OS}	91.30	91.28	91.01	90.57	90.00	89.33	88.58
$\Pi^{SG,\beta=0.4}_{OS}$	270.48	270.48	270.39	270.22	270.00	269.73	269.42

Table 3. Sensitivity analysis of three models with respect to *T*

T	300	350	400	450	500	550	600
l^{UD}	2.40	2.54	2.66	2.77	2.87	2.96	3.04
Π^{UD}	426.28	407.24	390.55	375.70	362.32	350.15	338.99
l^{GO}	0.20	0.34	0.47	0.58	0.67	0.76	0.85
Π^{GO}	602.91	583.86	567.18	552.33	538.95	526.78	515.61
l^{SG}	0.08	0.19	0.29	0.38	0.46	0.52	0.59
Π^{SG}	601.87	582.32	565.07	549.61	535.57	522.71	510.82
Π_{PM}^{UD}	72.25	55.32	40.49	27.29	15.40	4.58	-5.34
Π_{PM}^{GO}	335.92	318.99	304.16	290.96	279.07	268.25	258.32
Π_{PM}^{SG}	510.59	538.80	569.23	601.40	634.99	669.74	705.47
$\Pi_{PM}^{SG,\beta=0.2}$	271.65	261.83	254.38	248.74	244.55	241.53	239.50
Π_{OS}^{UD}	354.03	351.92	350.06	348.41	346.92	345.57	344.33
Π_{OS}^{GO}	266.99	264.87	263.02	261.37	259.88	258.53	257.29
Π_{OS}^{SG}	91.28	43.52	-4.16	-51.80	-99.41	-147.03	-194.65
$\Pi_{OS}^{SG,\beta=0.2}$	330.22	320.49	310.70	300.87	291.03	281.18	271.33

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Performance measures for evaluating last mile logistic solutions: a multi-stakeholder perspective

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Abstract

The purpose of this paper is to develop a methodology for the evaluation of Last Mile (LM) logistics solutions from the perspective of consumers, industry and institutional stakeholders. Previous studies have predominantly considered LM provision from an industrial supply chain perspective. This framework aims to capture the perspectives of multiple stakeholders operating within the urban environment to identify synergies where a collaborative approach to network design can lead to socio-environmental, efficiency and service benefits. The approach involves re-defining the role of institutional players that facilitate performance outcomes rather than a more traditional governance role. Similarly, industrial efficiency dimensions are focused around customer service outcomes. Finally, the research identifies a common set of metrics that integrates the three stakeholder groups, applied to B2B and B2C models.

NB: the full paper will be available online following the symposium

Performance Evaluation of Visual Management Case for Effective Technology Transfer

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Abstract
A visual management (VM) is now well known as one fashion and important management concept for smooth global supply chain management. A key target of VM is to harmonize communication among persons who have something to do with. For example, in case of a production sector, VM supports to resolve various burdens such as a quick detection of an abnormal situation, maintenance of a safety environment, a prevention of an operation miss and a knowledge sharing. However, a development of VM cases has been unrestrained. The situation is considered not good and it will be necessary to construct strategic enhancement system of VM. Based on the above recognition, as the initial step of the realization of the system, this paper discusses a quantification of a performance of VM cases.

Keywords: Visual Management, Performance Measurement, Technology Transfer, Multi-site Factory Management, Key Performance Indicators.

1. Introduction
These past few years, visual management (VM) is one fashion and important management concept. A key target of VM is to harmonize communication among coworkers, between the top manager and operators and among coworkers and customers through the visualization of various information, knowledge and values (Aki 2005). VM activities deliver a lot of effects. For example, in case of a production sector, VM supports to resolve various burdens such as a quick detection of an abnormal situation, maintenance of a safety environment, a prevention of an operation miss and a knowledge sharing.

When a supply chain network has been complicated under the recent rapid globalization, VM will become more important. However, a development of VM cases has been unrestrained and its situation is considered not good. Hence it will be necessary to construct strategic enhancement system of VM. Based on the above recognition, this paper focuses on VM in a production sector. And then, as the initial step of the realization of the system, this paper discusses a quantification of a performance of VM cases.

This paper consists of the following seven sections. Related literatures of a quantification of VM cases are reviewed in next section. A research procedure of this paper is described in the third section. In the fourth section, a profile of analyzed cases is illustrated. In the fifth section, a quantification of individual case is discussed and an application of the quantified data is described in the sixth sections and conclusions are made in the final section.

2. Strategic enhancement for visual management and its discussion points
An enhancement of VM will be expected to effectively utilize large-scale and complicated production systems. A visual factory (Greif 1991) is an innovative concept to extend an application range of VM form production sectors to other corporate sectors, including

administration, engineering and sales. In recent years, Parry and Turner (2006) estimated that VM tools are powerful tools for use beyond manufacturing. And they have been used in other industries. For example, lean construction are proposed as an extend theory of lean management in production sector (Sacks 2010) and a classification of VM cases in construction site is performed in Brazil (Tezel et al. 2010).

The reason of the above spread is that VM contributes to the maintenance and improvement of related key performance indicators (KPIs), i.e. reliability, productivity and safety. For instance, the balance scorecard is regarded as one of the VM tools for clarifying KPIs from their original four points of view (Kaplan and Norton 1992).

However, in production site where VM is more advanced than other sectors and industries, when a distribution of installed cases is checked in two relevant factories which have the same burden, it may be found that one don't know that the other has already solved the burden by an installation of VM case. It indicates the shortage of systematic enhancement of developed cases. In order to tackle with the problem, Murata and Katayama (2010 a, b) proposed a technology transfer system with VM case-base which is a kind of database. They mainly discussed how to construct the case-base. But there are few problems about a utilization of the system as follows.

- An effective supply of cases from constructed case-base to plural factories is not described.
- It is difficult to find useful case to improve a performance of each factory.
- It is difficult to consider a practical case transfer under the limitation of the management resources.

This paper proposes a mathematical model to transfer case from the case-base to plural factories after an individual case accumulated in the case-base is analyzed. And then an examination is performed to confirm the utility of the proposed model. In addition, on the analysis of the individual case, a past study is only one evaluation results (Murata and Katayama 2013). However it is necessary to analysis a case form a compound eye. In this paper, two kinds of evaluation are performed. And then a clarification of the difference between two evaluations and a combination of them is discussed.

3. Research procedure

Research procedure of this paper consists of two stages. The purpose of the first stage is three ways of characteristic analyses of developed cases (Figure 1). The first way is an analysis of a relationship between VM cases and KPIs from two viewpoints. The former is case's strong point to improve KPI and a relationship chart by 0-1 variable is made to quantify a performance of each case. The latter is case's comprehensive capability to improve KPI and a relationship chart is made by variable between 0 and 1 with a pairwise comparison. The second way is an analysis of a similarity among VM cases. In order to realize the analysis, two kinds of case scores are given by a quantification theory category III (Hayashi and Suzuki 1975) and an analytic hierarchy process (AHP) (Saaty 1977). And the third way is a discussion of a difference between two case score groups through considering how to make integrated case score.

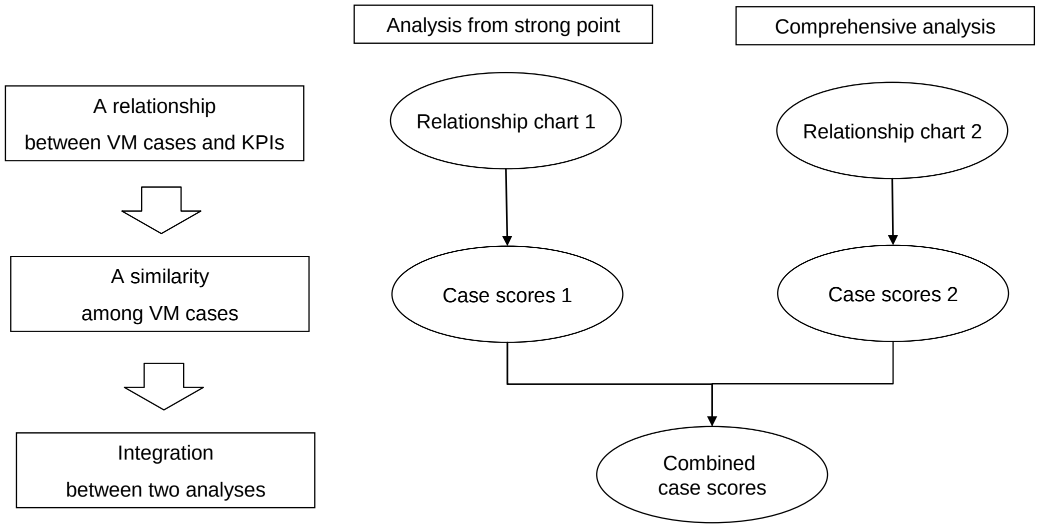

Figure 1. First stage for performance evaluation of visual management case

In the second stage, a plan to transfer useful cases to plural organizations is made based on the output of the first stage. For the planning, two systems are proposed quoted by a type of production system. One is "a push case transfer system". The other is "a pull case transfer system". Three descriptions of each system are performed as shown in Figure 2. First description is a framework of each system as how to use cross-sectional case-base where plural organizations have supplied cases. Second description is a mathematical model of case transfer which is used for both frameworks in common as a liner programming problem. Third description is two simulations by the proposed model. An output of first simulation is a basic material for "a push case transfer system". It is one recommend case from a cross-sectional case-base to plural factories. An output of second simulation is a basic material for "a pull case transfer system". It is frontier curve that indicates how to transfer case under various limitations of management resources.

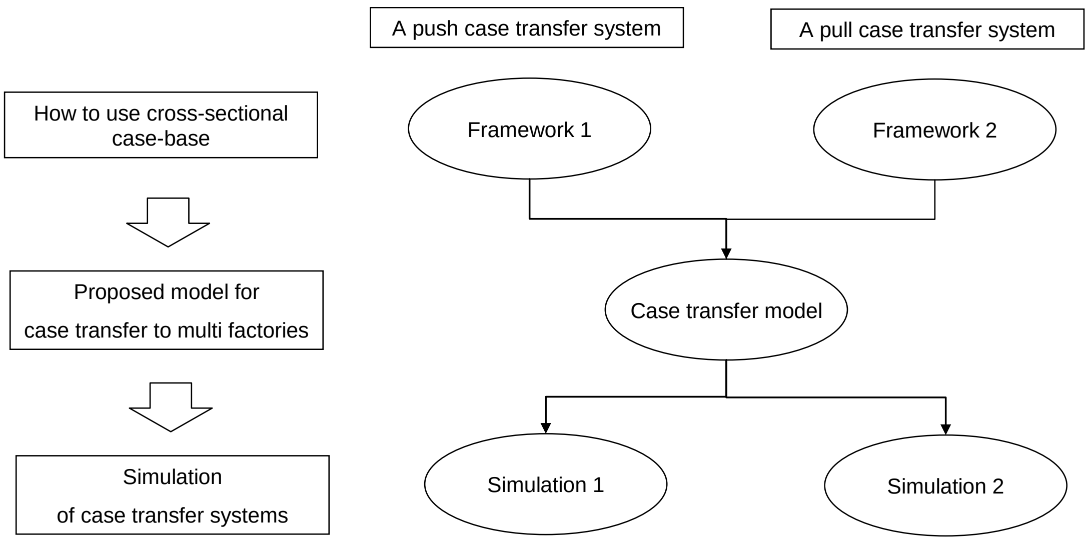

Figure 2. Second stage for performance evaluation of visual management case

4. Analyzed visual management case

One-hundred and forty-one visual management cases were collected via an investigation of four chemical plants, factory A, factory B, factory C and factory D in the collaborated company. They are the members of the constructed cross-sectional case-base. Table 1 shows a distribution of cases in the case-base. They are classified from the viewpoint of main improved KPI. Object performance indicator is seven KPIs; quality (Q), cost (C), delivery (D), productivity (P), safety/hygiene (S/H), environment (E) and morale (M). However definitions of KPIs can be interpreted in various ways, they are followed by Murata and Katayama (2013b) in this study. From the table, four factories are totally eager to develop cases to improve quality (Q) because a number of cases to improve quality of all factories are more than to improve other KPIs. As an additional remark, the table is used as a simulation data a_{hi} in section 6.

Table 1. Distribution of cases accumulated in the case-base (a_{hj})

Factory (*h*) / KPIs (*j*)	Factoy A	Factory B	Factory C	Factory D	Total
Q	13	17	14	11	55
C	3	4	2	7	16
D	1	1	3	3	8
P	3	7	14	5	29
S	1	2	5	3	11
E	1	1	2	2	6
M	1	3	2	10	16
Total	23	35	42	41	141

On the other hand, all cases are divided into ten groups as shown in Table 2. Cases which belong to the same group will resolve the similar burden. For example, eight cases of first group are useful for supporting an unskillful operation. Also, one representative case of every group is selected for the following analysis. The case numbers are 14, 24, 28, 54, 58, 63, 97, 117, 121 and 140.

Table 2. Contents of constructed case-base

Group	A number of cases	Main solved burden	Representative case
Group 1	8	Unskillful operation	case 14
Group 2	13	Operation at a high place	case 24
Group 3	16	Error in operating order	case 28
Group 4	27	Operation of similar objects	case 54
Group 5	11	Invasion into a restricted area	case 58
Group 6	29	Unusual measured values	case 63
Group 7	17	Shortage of knowledge	case 97
Group 8	7	Switching miss	case 117
Group 9	5	Forgetful maintenance point	case 121
Group 10	8	Many management points	case 140

5. Analysis of individual visual management case (First stage)

5.1 Relationship between cases and key performance indicators

A relationship between all representative cases and all adopted KPIs is made by outputs of the above two tables. Table 3 shows strong point every representative case. To be concrete, the first improved KPI and the second one of each representative case are clarified. In case of case 14, quality (Q) and productivity (P) are more improved than other KPIs.

Moreover, Table 4 shows a whole contribution of each case to all KPIs. They are found by a pairwise comparison with a chart of AHP hierarchy as shown in Figure 3. As a total trend, cases are mainly developed to improve quality (Q) because a total score of ten cases to improve quality (Q) (0.199) are the highest compared to scores of other KPIs. The result is agreed with a distribution of cases accumulated in the case-base as shown in Table 4 mentioned above. As an additional remark, the table is used as a simulation data w_{hi} in section 6.

Table 3. Relationship between representative cases and KPIs by 0-1 variable

Representative case \ KPI	Q	C	D	P	S	E	M
Case 14	1	0	0	1	0	0	0
Case 24	0	0	0	1	1	0	0
Case 28	1	0	0	0	0	1	0
Case 54	0	0	1	0	0	1	0
Case 58	0	1	0	0	1	0	0
Case 63	1	0	0	0	1	0	0
Case 97	0	1	0	0	0	0	1
Case 117	0	1	1	0	0	0	0
Case 121	0	0	0	1	0	0	1
Case 140	0	0	1	0	0	0	1

Table 4. Relationship between representative cases and KPIs by a value between 0 and 1 (w_{hi})

Representative case \ KPI	Q	C	D	P	S	E	M	u_i
Case 14	0.025	0.008	0.015	0.005	0.007	0.008	0.010	0.078
Case 24	0.026	0.003	0.013	0.015	0.019	0.006	0.007	0.089
Case 28	0.033	0.006	0.027	0.010	0.010	0.019	0.015	0.120
Case 54	0.027	0.007	0.039	0.012	0.013	0.022	0.014	0.133
Case 58	0.007	0.022	0.010	0.003	0.030	0.014	0.028	0.114
Case 63	0.014	0.003	0.014	0.006	0.005	0.007	0.009	0.057
Case 97	0.015	0.008	0.012	0.004	0.006	0.006	0.033	0.084
Case 117	0.022	0.011	0.036	0.010	0.011	0.020	0.011	0.121
Case 121	0.010	0.010	0.014	0.009	0.005	0.012	0.009	0.069
Case 140	0.020	0.015	0.031	0.010	0.012	0.021	0.025	0.135
Total	0.199	0.093	0.211	0.084	0.118	0.135	0.161	1.000

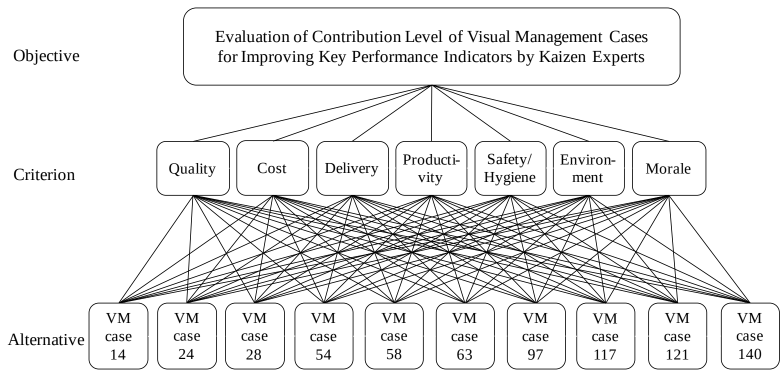

Figure 3. AHP hierarchy for a clarification of a relationship between VM cases to KPIs

5.2 Similarity among cases

Table 5 shows a measurement result of a similarity among ten objective cases. Case 140 (1.102) and case 117 (1.102) are one and over score cases about y_i. Main solved burden of each case is “many management points” and “a switching miss” from Table 2. It will be thought that they will occur everywhere in the factories. Therefore the case group is named “a support for common operations”. On the other hand, case 63 (-1.102) and case 14 (-1.102) are one and below score case about y_i. Main management object of each case is “unusual measured values” and “unskillful operations” from Table 2. The utilization situation of these cases seems to be under various unusual conditions. So the case group is named “a support for specific operations”. From the analysis mentioned above, y_i means “a universality of supported operation by VM cases”.

Scores of Table 4 are rearranged by orders of vertical and horizontal axes in Table 5 as shown in Table 6. When Table 5 and Table 6 are compared, case 117 and case 140 which have high score about y_i have superior score about u_i. In the same way, case 63 and case 14 which have low score about y_i have subordinate score about u_i. The two results indicate the same similarity of object cases on the whole. Moreover, when using u_i, multi-sided interpretation can be possible. For example, it is found that improved KPIs by case 140, one of the high score cases about y_i, is not only delivery (D) and moral (M) but also environment (E) and quality (Q) from the score of u_i.

Table 5. Result of scoring by Qualification Category III

	x_k	1.291	0.913	0.913	0.000	-0.913	-0.913	-1.291
y_i	KPI / Representative case	D	C	M	E	P	S	Q
1.102	Case 117	1	1	0	0	0	0	0
1.102	Case 140	1	0	1	0	0	0	0
0.913	Case 97	0	1	1	0	0	0	0
0.645	Case 54	1	0	0	1	0	0	0
0.000	Case 58	0	1	0	0	0	1	0
0.000	Case 121	0	0	1	0	1	0	0
-0.645	Case 28	0	0	0	1	0	0	1
-0.913	Case 24	0	0	0	0	1	1	0
-1.102	Case 14	0	0	0	0	1	0	1
-1.102	Case 63	0	0	0	0	0	1	1

Table 6. Table 4‘s score sorted by orders of vertical and horizontal axes in Table 5

KPI / Representative case	D	C	M	E	P	S	Q	u_i
Case 117	0.036	0.011	0.011	0.020	0.010	0.011	0.022	0.121
Case 140	0.031	0.015	0.025	0.021	0.010	0.012	0.020	0.135
Case 97	0.012	0.008	0.033	0.006	0.004	0.006	0.015	0.084
Case 54	0.039	0.007	0.014	0.022	0.012	0.013	0.027	0.133
Case 58	0.010	0.022	0.028	0.014	0.003	0.030	0.007	0.114
Case 121	0.014	0.010	0.009	0.012	0.009	0.005	0.010	0.069
Case 28	0.027	0.006	0.015	0.019	0.010	0.010	0.033	0.120
Case 24	0.013	0.003	0.007	0.006	0.015	0.019	0.026	0.089
Case 14	0.015	0.008	0.010	0.008	0.005	0.007	0.025	0.078
Case 63	0.014	0.003	0.009	0.007	0.006	0.005	0.014	0.057
Total	0.211	0.093	0.161	0.135	0.084	0.118	0.199	1.000

5.3 Integration between two case score groups

On the other hand, it is found that an interpretation of a case by one scoring is different from an interpretation of a case by the other scoring. In order to clarify the degree of the difference, a simulation for various combinations of two kinds of scores is performed by formula (1). It is

$$z_i = \alpha y_i' + (1-\alpha) u_i' \quad (1)$$

where z_i is combined scores, y_i’ is standardized scores of y_i, u_i’ is standardized scores of u_i, α is weight values between 0 and 1, and i is a suffix of a case. Moreover formula (2) is used to measure the degree of the difference. It is

$$s_i = |u_i' - y_i'| \quad (2)$$

where s_i is a slop of case i’s line which is made by moving α from 1 to 0. If s_i is large, the difference between two scoring of case i will be large.

From Figure 4 and Table 7, it is found that a quantification of the difference between two case score groups will be realized. When α is 1, if a condition of “a support group for common operations” is that z_i is 0.5 and over, case members of the group are 140, 117, 97, 54, 58 and 121. If a condition of “a support group for specific operations” is that z_i is less than 0.5, case members of the group are 28, 24, 14 and 63. When α is 0, if a condition of “a support group for common operations” is that z_i is 0.5 and over, case members of the group are 140, 54, 117, 28 and 58. If a condition of “a support group for specific operations” is that z_i is less than 0.5, case members of the group are 24, 97, 14, 121 and 63. From the results, as for three cases such as case 28, case 97 and case 121, a group which belongs to is changed.

Concerning the degree of the difference of the above three cases, s_i of case 97 (0.568) and case 28 (0.601) is particularly larger than other cases. When α moves from 1 to 0, the group of case 97 is changed from “a support group for common operations” to “a support group for specific operations” and the group of case 28 is changed from “a support group for specific operations” to “a support group for common operations”. An interpretation of a feature of two cases is certainly difficult. The reason is that the a rate of occurrence of supported burdens by two cases, “a shortage of knowledge” and “an error in operating order”, has changed by various conditions, i.e. an early stage on a busy production period, a mass-production of new product and a retirement of many experts and so on.

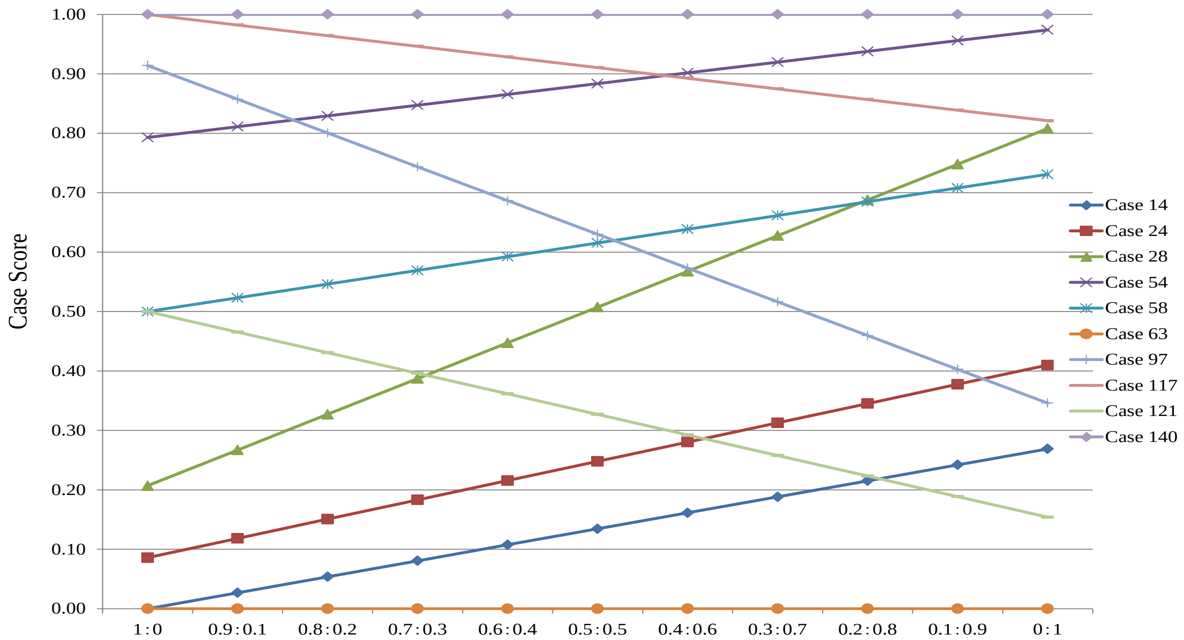

Figure 4. Simulation result of combined score (z_i)

Table 7. Case scores after standardization

Case	y_i’	u_i’	s_i
Case 140	1.000	1.000	0.000
Case 117	1.000	0.821	0.179
Case 97	0.914	0.346	0.568
Case 54	0.793	0.974	0.181
Case 58	0.500	0.731	0.231
Case 121	0.500	0.154	0.346
Case 28	0.207	0.808	0.601
Case 24	0.086	0.410	0.324
Case 14	0.000	0.269	0.269
Case 63	0.000	0.000	0.000

Furthermore the model is given to gain one of the optimal solutions of combined scores between two case score groups by the following formula (3)-(4). The model of the objective function is

$$C_1 = \min_{e,f} \sum_{i=1}^{n} (u_i' - z_i)^2 \tag{3}$$

where C_1 is the minimization of the total of a square of the difference between u_i' and z_i from case *i* to case *n*, u_i' is a standardized score of u_i, z_i is a liner transformation value of y_i', *e* and *f* are regulation values, *n* is a number of cases and *i* is a suffix of a case. A constrain of the model is illustrated from formula (4). It is

$$z_i = e y_i' + f \tag{4}$$

where z_i is a liner transformation value of y_i', y_i' is a standardized score of y_i, *e* is a regulation value (slope), *f* is a regulation value (intercept) and *i* is a suffix of a case. Moreover formula (5) is designed to evaluate the degree of the combination between y_i' and u_i'. It is

$$C_2 = \frac{\sum_{i=1}^{n} (u_i' - z_i)^2}{\sum_{i=1}^{n} (u_i' - y_i')^2} \tag{5}$$

where C_2 is a ratio of the total of a square of the difference between u_i' and z_i from case *i* to case *n* to the total of a square of the difference between u_i' and y_i' from case *i* to case *n*.

Calculation result is as follows. The value of the objective function C_1 is 0.734, *e* is 0.527, *f* is 0.288, and Table 8 shows score of z_i. The value of the evaluation function C_2 is 0.668. Hence a combination ratio of u_i' and y_i' in z_i are 0.668: 0.332.

Table 8. Combined case score (z_i)

Case	z_i
Case 140	0.815
Case 117	0.815
Case 97	0.769
Case 54	0.706
Case 58	0.551
Case 121	0.551
Case 28	0.397
Case 24	0.333
Case 14	0.288
Case 63	0.288

6. Effective utilization of plural VM cases among multi factories (Second stage)

6.1 How to use cross-sectional case-base

In order to use a case accumulated in cross-sectional case-base effectively, two systems are considered as follows. One is a recommendation system. A manager of a case-base analyzes a current burden of each factory and a potential capability of each case accumulated in a case-base. And then useful case which fits factory's needs is provided from the case-base to the factory. The system is considered as "a push case transfer system" liken to a typical production system (Sugimori et al 1997 and Womack 2003) as shown in Figure 5.

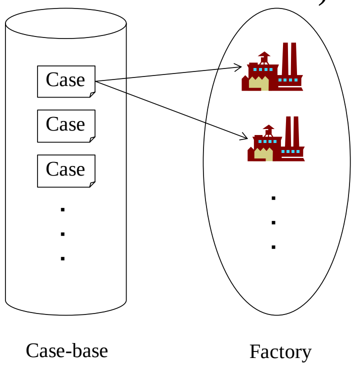

Figure 5. A push case transfer system with case-base

The other is a selection system. In case of the system, an effective application of the system depends on operators' capability and motivation in their factory. In other words, they should well investigate and understand current problems in their factory. And then, they retrieve suitable cases from a case-base based on their survey results. The system is considered as "a pull case transfer system" as shown in Figure 6.

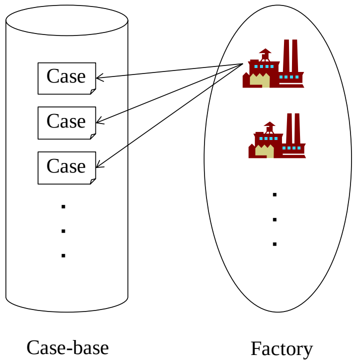

Figure 6. A pull case transfer system with case-base

6.2 Proposed model for case transfer to multi factories

A model is proposed to realize a systematic operation of a push case transfer system and a pull case transfer system mentioned above. A mathematical representation is given by the following formula (6)-(11). The purpose of the proposed model is the supply of a useful case to plural factories in the case-base. The model of the objective function is

$$\max J = \sum_{j=1}^{p} y_j \tag{6}$$

where J is the maximum of the contribution degree of all assigned cases in all factories, y_j is the contribution of assigned cases in factory j, P is a number of factories and j is a suffix of factory. Constrains of the model is illustrated from formula (7) to formula (11). Formula (7) is

$$y_j = \sum_{i=1}^{n} b_{ij} x_{ij} \quad (j = 1, \ldots, P) \tag{7}$$

where b_{ij} is the contribution degree of case i in factory j, x_{ij} is decision variables; if case i is assigned to factory j, x_{ij} is 1 and if case i is not assigned to factory j, x_{ij} is 0, n is a number of cases and i is a suffix of case. Formula (8) is

$$b_{ij} = \sum_{h=1}^{m} (1 + A_{hj}) w_{hi} \quad (i = 1, \ldots n, j = 1, \ldots, P) \tag{8}$$

where A_{hj} is an impact coefficient to improve KPI h in factory j, w_{hi} is the contribution degree of case i to KPI h, m is a number of KPIs, h is a suffix of KPI. Formula (9) is

$$A_{hj} = \frac{a_{hj}}{\sum_{h=1}^{m}\sum_{j=1}^{P} a_{hj}} \qquad (h = 1,..., m,\ j = 1,..., P) \tag{9}$$

where a source data for a_{hj} is obtained from quantified information in the cross-sectional case-base. Namely, a_{hj} is a number of cases to chiefly improve KPI h in factory j in the case-base. Because of how to calculate A_{hj} like this, the proposed model is recognized as a strong point of each factory. As other constrains, formula (10) and formula (11) is as follows. Formula (10) is

$$lc_j \le \sum_{i=1}^{n} x_{ij} \le uc_j \quad (j = 1,..., P) \tag{10}$$

where uc_j is a upper limit of a number of assigned cases to factory j and lc_j is a lower limit of a number of assigned cases to factory j. It means the condition of a workload of each factory to install assigned cases. Formula (11) is

$$lf_i \le \sum_{j=1}^{P} x_{ij} \le uf_i \qquad (i = 1,...n) \tag{11}$$

where uf_j is a upper limit of a number of factories to assign case i and lf_j is a lower limit of a number of factories to assign case i. It means the condition of an application range of each case.

In next two chapters, simulations are performed in case of a push case transfer system and a pull case transfer system by the proposed model.

6.3 Simulation for a push case transfer system

Preconditions of the simulation are set up based on information of the object case-base described in section 4; a number of factories P is 4, a number of cases n is 10, a number of KPIs m is 7, Table 1 is used for a_{hj} and Table 4 is used for w_{hi}. Also formula (10) and formula (11) become formula (12) and formula (13) respectively for expressing a push case transfer system.

$$\sum_{i=1}^{4} x_{ij} = 1 \quad (j = 1,...,4) \tag{12}$$

$$0 \le \sum_{j=1}^{4} x_{ij} \le 4 \quad (i = 1,...10) \tag{13}$$

Table 9 shows a simulation result. The value of the objective function J is 0.556. Case 54 is recommended to three factories such as factory A, B and C. And case 140 is recommended to factory D. All four factories eagerly improve a performance related to a quality from a value of a_{hj} of each factory as shown in Table 1. In addition, from Table 1, factory C is good at a productivity improvement and factory D is good at a moral improvement. On the other hand, a total contribution degree of two assigned cases, case 54 and case 140, is higher than other cases from Table 4. Moreover, compared to other cases, case 54 contributes to improve a performance related to productivity and case 140 contributes to improve a performance related to moral. From the analysis, the simulation outcome will be considered as an appropriate selection.

Table 9. Result of simulation for a push case transfer system (x_{ij})

Case \ Factory	A	B	C	D	Total
Case 14	0	0	0	0	0
Case 24	0	0	0	0	0
Case 28	0	0	0	0	0
Case 54	1	1	1	0	3
Case 58	0	0	0	0	0
Case 63	0	0	0	0	0
Case 97	0	0	0	0	0
Case 117	0	0	0	0	0
Case 121	0	0	0	0	0
Case 140	0	0	0	1	1
Total	1	1	1	1	4

6.4 Simulation for a pull case transfer system

In compared with preconditions of the simulation for the first simulation, formula (10) and formula (11) are modified to formula (14) and formula (15) respectively. They are set to observe various situations in a pull case transfer system. And then a random simulation is performed by changing a range of the two constrains. A number of simulation times are one thousand times.

$$0 \le \sum_{i=1}^{10} x_{ij} \le 10 \quad (j = 1,...,4) \tag{14}$$

$$0 \le \sum_{j=1}^{4} x_{ij} \le 4 \quad (i = 1,...10) \tag{15}$$

Figure 7 shows the result of the simulation. In case that a number of installed cases are fixed, it is found that values of the objective function are different every simulation results. For example, when a number of installed cases are 26 cases, the maximum value of the objective function is 2.99, the minimum value of the objective function is 2.53 and a range between two values is 0.46. In the case, the difference in an effect of case transfer is 18%. From the result of the analysis, a need for a strategic case transfer is recognized. Also predicated frontier curve like Figure 7 will be useful as a basic material to realize the need.

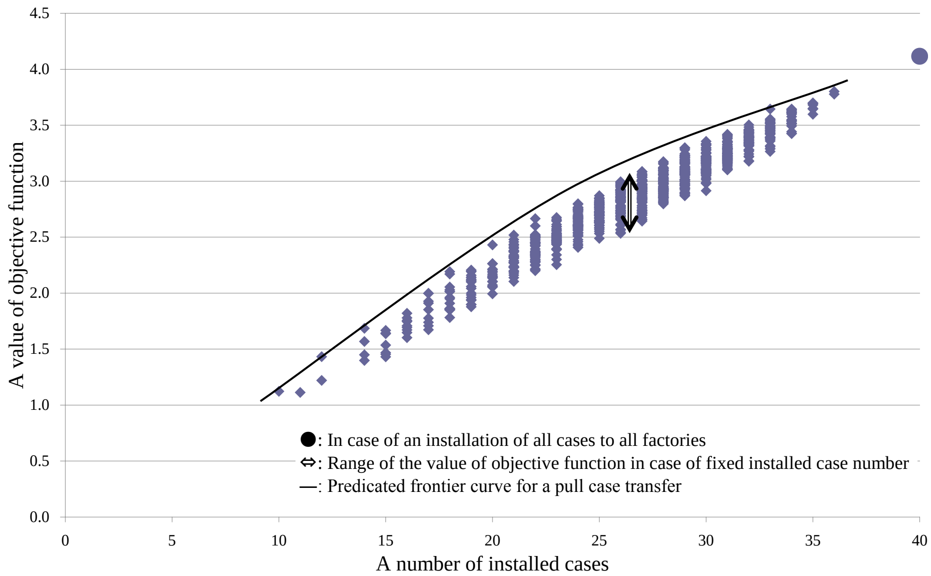

Figure 7. Result of simulation for a pull case transfer system (x_{ij})

7. Concluding remarks

In this paper, after individual VM case is quantified and analyzed, the assignment model of VM cases are proposed to improve KPIs in multi-site factories for two ways of case transfers such as a push type and a pull type. And then, the utility of the proposed model is confirmed by simulations with collaborative firm. This study has three contributions.

1. The proposed method of individual VM case analysis is one new method on how to clarify the difference between two case scores and how to combine them.
2. Proposed VM transfer ways, a push case transfer system and a pull case transfer system, will be added to develop a theory of a strategic enhancement of VM.
3. VM case transfer from the case-base to plural factories is systematic by a mathematical programming.

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Performance and Time Based Robustness Measures for Dynamical and Multi-variant Manufacturing Systems

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1. Introduction

In the face of emerging manufacturing complexity, manufacturing systems are increasingly susceptible to fluctuations and disruptions. Thus robustness, "the ability of a system to maintain specified features when subject to assemblages of perturbations either internal or external" (Jen, 2005), is recently regarded as a desirable characteristic to achieve in manufacturing systems, similar to flexibility or adaptability. Rendering the performance of a manufacturing system (e.g., throughput time, delivery reliability) robust to fluctuations and disruptions is regarded as beneficial as it ensures a constant output.

In the context of manufacturing systems research, different approaches and measures exist to render manufacturing systems robust, usually concerning specific, classical manufacturing problems, such as robust planning and scheduling (Kouvelis et al., 2000), or robustness of product quality. However, these approaches are usually not concerned with the overall robustness of the manufacturing system performance, but rather with the robustness of certain target values, i.e. product quality robustness or schedule robustness. In addition to that, there are only few definitions that take into account that a robustness measure should include a time component, i.e. a clear definition for which time span a measure needs to stay on which level in order for the system to be called robust.

In a previous paper, we have suggested to assess the robustness of a manufacturing system by modeling the manufacturing systems as a dynamically changing network of material flow (Becker et al., 2013). We defined manufacturing system robustness as the ratio of operations feasible under disruptions of a specific machine to total operations usually conducted in the system. The time component has only implicitly been included by the choice of the size of the time span for robustness assessment.

In this paper, we first present an overview of robustness concepts and measures in different research fields and in the context of manufacturing systems. We then proceed to suggest a measure to adequately quantify the robustness of manufacturing system performance. Due to the two-dimensional characteristic of robustness, namely the degree of maintaining performance and the time span allowed until recovery, we enhance our previously developed measure by an explicit time component. We explain the parameterization of our method and illustrate its applicability using a simulated flow-shop scenario.

2. Robustness Concepts and Measures

2.1 Robustness as a general system characteristic

The Oxford Dictionary of English defines the term “robust” in the context of systems or organizations as “able to withstand or overcome adverse conditions” (Stevenson, 2010). On a systemic level, robustness can be seen as a system property or systems-level phenomenon (Kitano, 2004), similar to other system characteristics such as flexibility or adaptability. Since there are a variety of research fields that explore or seek robustness for their respective systems, be it natural or engineered systems, a vast amount of robustness definitions and measures exists in literature. For many of these research fields, robustness can be generally defined as “the ability of a system to maintain specified features when subject to assemblages of perturbations either internal or external” (Jen, 2005). A further definition that assesses robustness as a system characteristic is the one of Kitano, which sees robustness as a “property that allows a system to maintain its functions despite external and internal perturbations” (Kitano, 2004).

As already mentioned, a variety of research fields or research methods are somehow related to robustness, some even incorporate the term “robustness” or “robust” in their title, such as robust control or robust statistics. In the following, we will give a selection of examples for research fields that are related to robustness and their corresponding robustness concepts.

2.2 A selection of robustness concepts in different research fields

2.2.1 Robust optimization

The term robust optimization subsumes research approaches that “search for designs and solutions that are immune with respect to production tolerances, parameter drifts during operation time, model sensitivities and others” (Beyer and Sendhoff, 2007). Such approaches have developed independently in various research fields. Beyer and Sendhoff categorize them into approaches from Operations Research and Engineering and give a detailed and comprehensive survey review on them (Beyer and Sendhoff, 2007).

In Operations Research, one of the first papers that is concerned with robust optimization suggests a mathematical optimization model which is able to deal with uncertain input data and is thus named “robust optimization” (Mulvey et al., 1995). Usually, a mathematical optimization model minimizes or maximizes a specific target function with respect to some constraints, given a definite set of input data. Mulvey et al. define that a solution to their robust optimization model is “solution robust if it remains close to optimal for all scenarios of the input data, and model robust if it remains “almost” feasible for all data scenarios” (Mulvey et al., 1995). Further works have extended this robust optimization model to robust linear, robust quadratic, and robust semidefinite programming (Ben-Tal and Nemirovski, 2002, 1998; Ben-Tal et al., 2009). Robust optimization models based on mathematical programming are applicable to problems from a wide range of fields, e.g., finance, computer science, and most prominently engineering. A detailed review and categorization focusing on robust optimization in Operations Research is given by Roy (Roy, 2010).

Other fields with particular interest in robust optimization are different engineering disciplines, where robust optimization is also referred to as robust design optimization. These approaches mainly search for a robust design of structures such as buildings or mechanical systems (Doltsinis and Kang, 2004; Sandgren and Cameron, 2002). Here it has to be thoroughly differentiated between reliability based design optimization and robust design optimization.

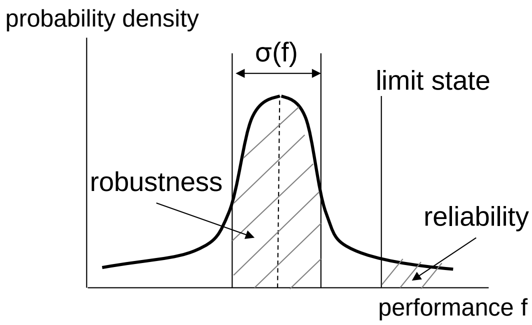

Figure 1: The difference between structural robustness and reliability (Doltsinis and Kang, 2004)

In robust design, the aim is rather to reduce the variability of structural performance caused by regular fluctuations, and does not primarily aim at avoiding catastrophe in the case of extreme events. Therefore, as illustrated in Figure 1, robustness is assessed by the measure of the performance variability around the mean ($\sigma(f)$). Contrary to that, reliability is measured as the probability of failure occurrence after a certain limit state (Doltsinis and Kang, 2004).

Beyer & Sendhoff categorize the robust optimization approaches in engineering in two main classes: those using numerical techniques to calculate the desired robustness measures and the related constraints and those that treat uncertainties directly by optimizing noisy functions and constraints (Beyer and Sendhoff, 2007).

2.2.2 Robust design

A further term that refers to approaches concerned with robustness in quality engineering is robust design, also often referred to as robust parameter design. It is a “method for improving product or manufacturing process design by making the output response insensitive (robust) to difficult-to-control variations (noise)” (Tsui, 1999). It was developed and popularized by Genichi Taguchi in the 1980s (Taguchi, 1986). He defines robustness as "the state where the technology, product, or process performance is minimally sensitive to factors causing variability (either in the manufacturing or user's environment) and aging at the lowest unit manufacturing cost" and proposes to use the signal to noise ratio as a robustness measure (Taguchi et al., 2000).

Enhancing Taguchi’s initially proposed method, (Chen et al., 1996) introduce two different types of robustness in robust design that are associated with minimizing performance variations and at the same time bringing the mean performance on target, which they name type I and type II robustness. Type I robustness minimizes “variations in performance caused by variations in noise factors (uncontrollable parameters)", while Type II robustness minimizes "variations in performance caused by variations in control factors (design variables)" (Chen et al., 1996). An illustration of Type II robustness is given in Figure 2. Here the performance deviation is shown as a function of one design variable x. In this Type II robust design, it is aimed at reducing the variation of the response of the performance deviation caused by variations of design variables (μ_{robust}), and not to move the performance function towards a minimal value (μ_{opt}).

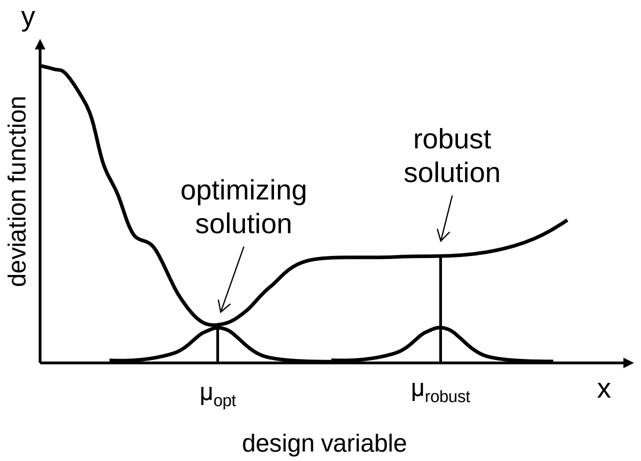

Figure 2: Type II robust design (figure slightly altered from (Chen et al., 1996))

Robust design approaches have since their introduction quickly gained immense popularity in engineering (a first review paper already appeared in 1992, (Tsui, 1992)), and many approaches have enhanced what was initially suggested by Taguchi with Response Surface Modelling (RSM) or mathematical programming approaches (e.g., (Chen et al., 1996; Dellino et al., 2010)). Such approaches however can rather be counted in the domain of robust optimization than in the area of robust parameter design. Although some approaches using Taguchi methods use the expression "robust design optimization" to describe their work (e.g. (Sundaresan et al., 1992)), such approaches should not to be confused with robust optimization methods, as many of them do not technically make use of mathematical optimization but of experimental design procedures (Sandgren and Cameron, 2002).

2.2.3 Robustness measures in the field of manufacturing systems research

Robust production control methods are control methods to organize release and routing of production orders so that fluctuations and disturbances do not negatively influence the performance of the manufacturing system. Telmoudi et al. (2008) suggest a framework for robust control laws in manufacturing and define manufacturing system robustness 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). Kleijnen and Gaury (2003) define robustness as the "[production pull control systems] capability to maintain short-term service while minimizing long-term work-in-process, under a variety of scenarios".

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. Kouvelis et al. (2000) 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 define “a schedule whose performance does not significantly degrade in the face of disruption” (Sabuncuoglu and Goren, 2009) 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. 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) (Scholz-Reiter et al., 2011). The stability radius describes the smallest change of parameter that destabilizes a system. In a similar way, (Sharda and Banerjee, 2013) suggest a robust manufacturing system design approach for robust configurations of machines (e.g., number and type) under uncertainties such as processing times, arrival times, machine failure and repairs, and product demand. Mondal et al. (2014) present a detailed overview of suggested measures for evaluation of the robustness of manufacturing processes, mostly based on robust design approaches (see section 2.2.2). In a more holistic approach, we previously suggested to consider robustness in manufacturing systems as a characteristic of the overall system, rather than for example 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. Modelling performance and time-related manufacturing system performance robustness

As stated in many of the previously cited works, robustness allows a system to maintain a specific feature or function in the face of perturbations. Usually, this feature or function to be maintained is declared to be a specific value of system performance. In addition to that, the perturbations against which system robustness should buffer also have to be specific variables, i.e. it has to be defined against what kind of perturbations a system is robust. In a previous approach, we defined the executed machine operations as a performance value and the disruption of a machine as the perturbations. We then used the ratio of remaining machine operations executed in a perturbed scenario and machine operations carried out in an unperturbed scenario as an indicator for system robustness (Becker et al., 2013). However, this did not take into account that in a manufacturing environment, perturbations are usually related to a time-component, i.e. a machine disruption will usually only last for the time it takes to repair or replace the disrupted machine. We therefore now suggest to relate system robustness not only to a static value (e.g. a one time machine disruption), but to also explicitly consider a time-component in the robustness definition. A performance reduction caused by a disruption does not necessarily imply that the system itself is not robust. In fact, the duration of disruption or rather the severity of the impact of the disruption on the performance is important when defining whether a system is robust or not. In addition to that, a slight change in system performance should not directly lead to the system being classified as not robust. It should rather be possible for the performance to slightly fluctuate in a defined tolerance corridor.

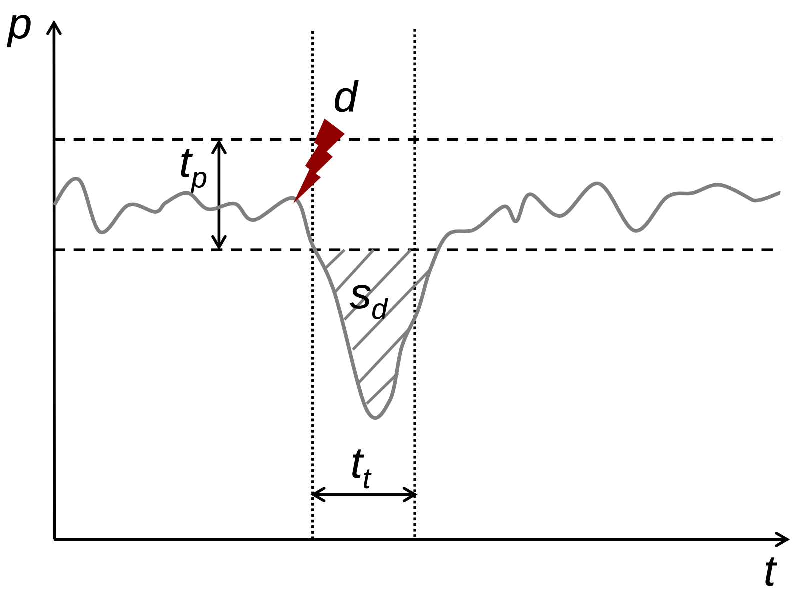

Figure 3: System performance (*p*) and its dependence on time (*t*). *p* fluctuates in defined tolerance corridors for performance (t_p) and time (t_t). *d* denotes the occurrence of a disruption while s_d represents the severity of the disruption.

Figure 1 illustrates how the time-dependent system performance (*p*) sinks below a set performance tolerance level t_p as a cause of a disruption (*d*). The performance can fluctuate within the span of t_p and the performance reduction can last for the span of t_t before the system is not considered to be robust any more. Yet when the disruption induced performance reduction stays under the performance threshold longer than the tolerance span t_t, robustness is not given. The area between the performance curve and the lower performance tolerance level can be described as the severity of the disruption, s_D.

4. Experiments

4.1 Experiment Setup

In order to test and demonstrate the application of the proposed robustness measure, we perform a simulation study using a minimal flow-shop model developed by Blunck et al. (2014). We simulate the material flow behavior of 200 instances of a randomly created flow-shop manufacturing model. In each simulation run, one machine breaks down and undergoes repair for a constant amount of time, thus not being able to serve any products. The breakdown results in a temporary drop of the system performance. We record the percentage of simulated systems that fail to meet our previously defined robustness requirements for varying parameters t_t and t_p to demonstrate the sensitivity of a manufacturing system with respect to the two parameters. The random generation of the flow-shop models works as follows: There are four manufacturing stages, with each stage having up to 4 work stations. Four product variants are created, and each variant is randomly assigned to one of the four possible machines per stage, thus creating a directed flow of material through the four stages for each product. Due to the random selection of the work stations, not all work stations are necessarily selected for operation. Figure 2 illustrates one randomly created instance of the flow-shop model.

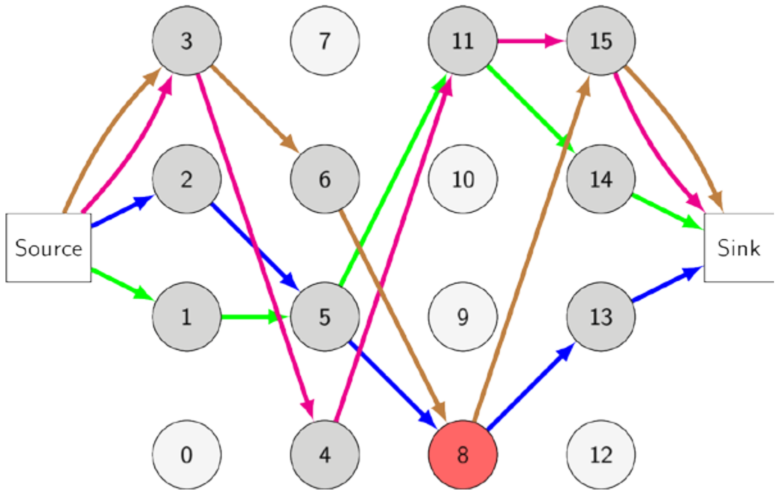

Figure 4: A single instance of a randomly created flow-shop model. Each variant (brown, magenta, blue, green) has a distinct path of material flow. The dark grey work stations are used in the manufacturing process of at least one variant, while the light grey work stations are not used in this instance. One machine out of the operative machines is randomly selected to break down for a constant amount of time in the middle of the simulation, resulting in a temporary decline in performance.

In this example, 11 of the maximum possible 16 work stations are operative. The colored arrows indicate the paths of the material flow of the four different variants. The active machines are dark grey, while the non-active machines are light grey (as they are not required to manufacture a certain variant, these machines are not participating in this instance of the simulation). The red work station is also active, but experiences a breakdown in the course of the simulation. All variants have an operation time of 1 time unit on each work station. The different variants are released into the manufacturing system using Poisson-distributed inter-arrival times at different rates. The release rate of a product $i \in \{1,..,4\}$ is $\alpha^{(i-1)}$ times the release rate of product 1, with $\alpha = 1.4$ and an initial release rate of product 1 of 0.15 products per time step. The manufacturing of a new variant at a work station requires a setup of 0.2 time units, and the variants are processed in batches of 4. As soon as 4 items of one variant are waiting at a work station, a batch is formed and the batches are processed on a FIFO (first-in-first-out) basis. Each of the 200 simulation runs lasted 500 time steps. The breakdown at the randomly selected machine occurred at time 250 and lasted 50 time units. Figure 3 depicts the development of the buffer inventory at each work station during a simulation run in the model from Figure 2. The breakdown event is indicated by a dashed line at time 250. It can be observed that the defective work station 8 collects buffer inventory, which is cleared again after approximately 100 time steps. Consequently, the performance of the whole system is affected for at least this period of time.

Figure 5: The inventory of all active machines during a simulation run. The breakdown of machine 8 occurs at time 250, followed by a temporary accumulation of inventory.

We illustrate the concept of the two-dimensional system robustness assessment using again the exemplarily selected simulation instance. Figure 4 shows the development of the performance of the system, measured by the moving average of the orders' cycle time. The time window to determine the moving average has been set to 25 time units, the average cycle time. The higher the average cycle time, the worse is the performance of the manufacturing system. The performance corridor (the horizontal corridor with size t_p) is centered around the median of all performance values in the time series. Figure 4 (a) illustrates the case if we select high values for both tolerance parameters, the performance tolerance t_p and the time tolerance t_t. The performance tolerance corridor is large enough to tolerate the fluctuations of the cycle time in the normal operation regime of the system. Although the breakdown of work station 8 causes fluctuations above the threshold of t_p, the selected value of t_t is large enough to tolerate a deviation across the limits of t_p. Therefore, the system can be considered *robust*. The performance situation in (b) is identical, but t_p is reduced in comparison to scenario (a). The narrow performance tolerance corridor would not consider the system as robust, even without the disturbance. However, as t_t is large enough, it compensates the fluctuations during the breakdown-period (as well as the other minor deviations), so that the system is *robust*. Scenario (c) illustrates the case of a large t_p in combination with a low t_t. The reduced time tolerance does not completely 'cover' the period of fluctuation caused by the breakdown. Consequently, the system is considered to be *not robust*. Finally, Figure 4(c) shows the robustness assessment with both parameters set to a low value. Neither t_p nor t_t are large enough to tolerate the intensity and the duration of the performance deviation, and the system is *not robust*.

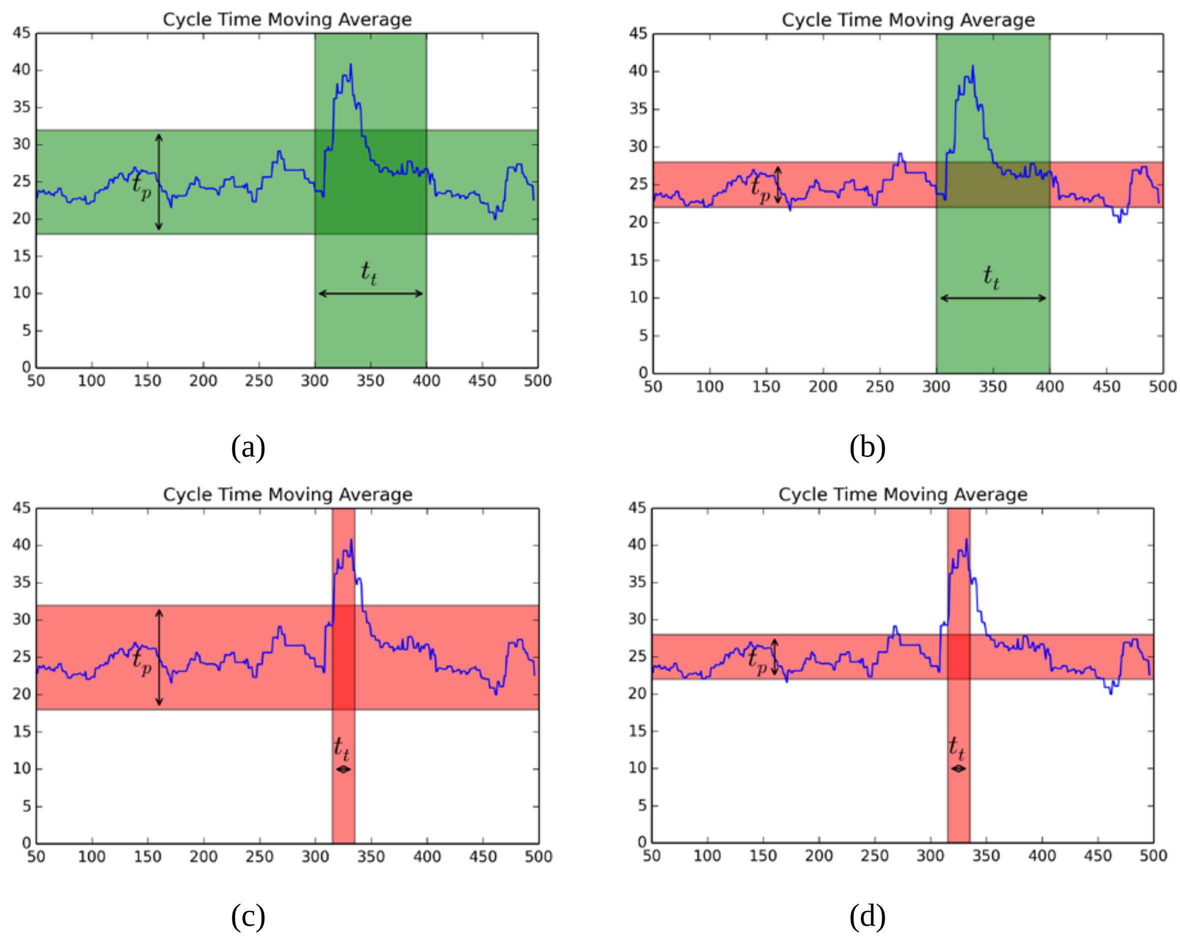

Figure 6: (a) Performance tolerance (t_p) and time tolerance (t_t) 'cover' the fluctuations, thus the system is robust. (b) t_p is not large enough, but t_t compensates for this, and the system is robust. (c), (d) Regardless of t_p, t_t cannot compensate for the duration of the performance deviation. Only a much higher value of t_p would prevent the system from being not robust.

4.2 Experiment Results

For the investigation of the sensitivity between the two parameters and the robustness of the complete system, we have carried out 200 simulation runs, each with the previously described configuration. The random initialization of each simulation run generates a new material flow situation for every instance, and consequently a slightly different performance development. If we see robustness from a classical, one-dimensional view, we would have different outcomes for the performance robustness R_p of the complete system depending on the selection of the performance tolerance t_p. For the robustness evaluation in this study, we consider the robustness value $r_{p,i}$ of a single simulation instance i to be

$$r_{p,i} = \begin{cases} 1 & if\ the\ system\ is\ considered\ robust \\ 0 & otherwise \end{cases} \tag{1}$$

The robustness $r_{p,i}$ is determined as described in the previous section, but only considering t_p: if the moving average of the performance (the cycle time) stays within the corridor, $r_{p,i} = 1$. The overall robustness R_p is the mean over all 200 simulation instances:

$$R_p = \bar{r}_{p,i} \ \forall \ i \ \in \{1, \ldots, 200\} \text{ with } 0 \ \leq \ R_p \ \leq 1 \quad (2)$$

The results from the simulation experiment show a rather linear development of the system robustness with respect to the selected performance tolerance, as illustrated in Figure 5. The problem of this measure is the fact that it solely considers the severity of the deviation, but not the duration of the performance deviation.

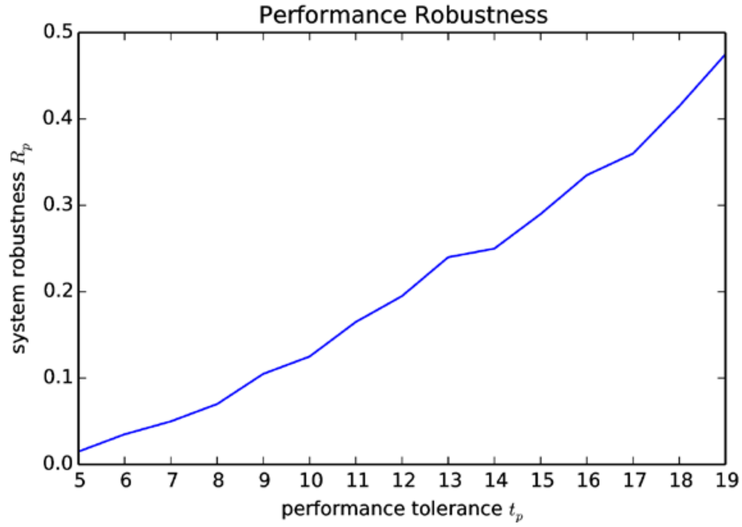

Figure 7: The performance robustness as a single, one-dimensional measure only considers the severity of the fluctuations (or even only a single fluctuation) for the robustness assessment

To assess the sensitivity of our two-dimensional robustness measure, we have used the same evaluation procedure as for the one-dimensional case presented in Equations 1 and 2. However, this time the robustness $r_{p,i}$ is determined considering t_p and t_t: if the moving average of the performance (the cycle time) stays within the corridor *and* possible deviations do not last longer than t_t, we set $r_{p,i} = 1$ (analogous to the example presented in Section 4.1). The system robustness $R_{p,t}$ is again the mean of $r_{p,i}$ over all instances.

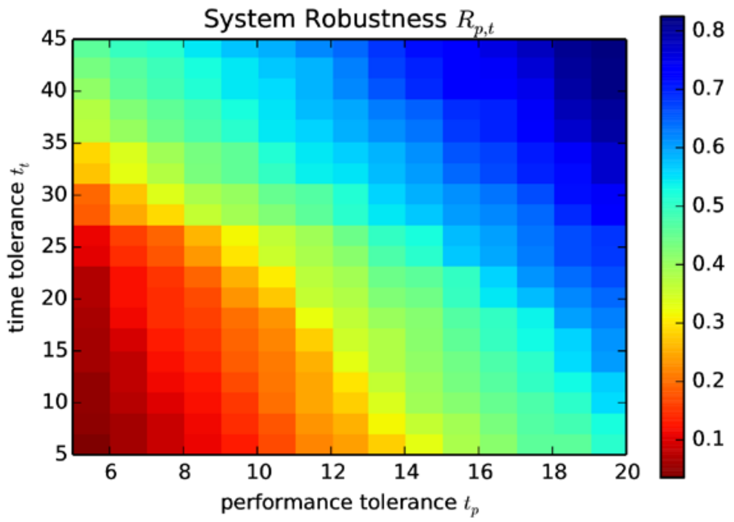

Figure 8: The overall system robustness is composed of the two dimensions, performance tolerance and time tolerance. In contrast to the one-dimensional measure in Figure PR, the time tolerance parameter allows to relax the robustness requirements for a more realistic assessment of robustness.

The evaluation of the system robustness is depicted in Figure 6. It can be observed that the overall robustness value increases when t_p or t_t increases. With the two-dimensional approach, a more realistic robustness is achieved, because short-term deviations, which are quickly resolved, are no longer considered as disruptions. In our concrete simulation example, the average cycle time of the products was approximately 25 time units. Figure 5 shows that even for large performance tolerance values such as $t_p = 20$ (which allow cycle time fluctuations between 60% and 140% in our simple scenario), the robustness measure $R_{p,t}$ reaches not more than 0.5. In contrast, if we allow a realistic reaction time for the system to recover (e.g., $t_t = 25$, which is one average cycle), the robustness measure increases about 0.3 to nearly 0.8 (as shown in Figure 6).

5. Conclusion

Robustness is a widely used term in many disciplines and for many purposes. In the field of manufacturing, there are different perspectives on the phenomenon of ‘robustness’, such as quality, performance, or scheduling. Therefore, whenever the term ‘robustness’ is used in manufacturing, a clear definition and disambiguation is necessary. We relate the robustness of a manufacturing system to the stability of its performance, i.e. the output of the complete system. Classical measures for robustness, such as the variance of the output or the definition of thresholds for the output deviation are one-dimensional: they only measure if there is a deviation or not. However, we claim that a system can still be robust if the duration of the deviation is within an acceptable limit. For this purpose we extend the existing idea of allowing a certain deviation from the performance value by a temporal ‘buffer’, in which deviations can be higher for a short period of time. Consequently, manufacturing system with the ability to quickly compensate deviations can be considered as robust. It is important to note that this time buffer should only allow short-term fluctuations, because we do not intend to include long recovery phases into our interpretation of robustness.

Our simulation experiments in a multi-variant flow-shop scenario have shown the applicability of the measure and its sensitivity towards the two parameters. Companies can use our measure and set their own tolerance parameters. The system robustness value can also be recorded separately for different processes, variants, or shop floors, so that the robustness of different parts of the company is made transparent. Our future research aims at investigating the behavior of our measure in more complex situations with different patterns of fluctuations. Furthermore, we want to define procedures for specifying the optimal tolerance values based on recorded manufacturing data.

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Proposing a virtual operations network to support a business policy for the Medicinal and Aromatic Plants sector

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Abstract
This research found out a more robust conceptual basis behind three missing links concerning the requirement for a virtual operations network to support a business policy for the Medicinal and Aromatic Plants (MAP) sector. Industry was pictured from secondary data gathered from a 12 experts panel. The factors to configure a collaborative network, e.g. relationships and structure, enabled the operationalisation of a previously defined social platform. Requirements for information infrastructure, co-ordination and DSS were also expressed. Moreover, the role of enterprise knowledge to the formation of collaborative ventures helped the modelling of the social-momentum of the platform. Finally, it is argued (i) for the confirmation of a significant Operations Management contribution to defining a MAP policy and, (ii) for the outlining of a collaborative network representing an advance to the usually ambiguous prescriptions of virtual operations. An interview guide to run an empirical test could be generated as further work.

Keywords: Collaborative network specification; Medicinal and Aromatic Plants (MAP) business policy, social platform operationalisation, virtual operations network.

1. Introduction

This research proposal attempts to justify a business policy supported by a collaborative operations virtual network for the Medicinal and Aromatic Plants (MAP) sector, in Portugal. It starts by addressing the potential business interest of MAP and by establishing the scope of organic MAP. Then, the presentations and minutes of a high-level meeting organised by public entities enabled to empirically picture the state of the art of the business sector, by listening to the stakeholders voice. Data is further organised into five categories, as follows: *Market and competitive environment*, *New product development and R&D*, *Collecting and treating data about the sector*, *Production*, and *The supply chain appeal*.

The next step is to analyse the current business requirements, by generating as an outcome three significant missing links. These pointed out a virtual supply chain as a conceptual operations model adequate to fulfil the needs of "*fileira*" and so, addressing the requirements expressed by a panel of experts for the MAP business. Furthermore, the existing social platform is considered an entrepreneurial initiative requiring formalisation as a collaborative partnership, where different types of partners are identified. There also is a final requirement to operationalise a technological platform to support the conceptual proposal for MAP.

In the final section, before conclusions, the ideas coming from the identified missing links in the results analysis are examined by positioning them in the scope of the adequate knowledge areas. The purpose of the exercise is to check its interest, to complete them and to build up a more robust conceptual basis. Thus, the SC fundamentals are revisited, the competitive environment is reviewed, the concept of virtual enterprise is comprehensively defined and collaborative processes are specified. This specification addresses not only the network configuration factors, but also the technical challenges of a collaborative network and the definition of knowledge in a collaborative context.

A final conclusions section closes the paper arguing for the contribution of Operations Management to the definition of an effective business policy, also pointing out the development of a questionnaire based on this assignment as a relevant inquiry tool to elaborate a diagnosis and an adequate collaborative network proposal.

2. Setting the business context for organic Medicinal and Aromatic Plants (MAP)

Definition and use of MAP

Many plant species are primarily used for their medicinal or aromatic properties in pharmacy or perfumery products, and because of that, they are defined as Medicinal and Aromatic Plants (MAP) in the EU (Verpoorte et al., 1999; Gomez-Galera et al., 2007). These MAP are a rich source of secondary metabolites which account for those properties and many of those plants are cultivated in order to obtain the natural constituents that are used in the production of fine chemicals or specialty products (Das, Raju, and Gutam, 2008).

For thousands of years, the natural plant products have been utilized for human healthcare in the form of drugs, antioxidants, flavours, fragrances, dyes, insecticides and pheromones. However, the use of synthetic drugs has led to a reduction in the consumption of plant-derived compounds, throughout the last century. Nevertheless, in recent years the consumption of MAP has increased, firstly because the synthetic drugs have side effects that are not found in plant-derived medicines, and secondly because there is a growing demand of the markets for high quality natural products, such those offered by MAP (ECPGR, 2014).

Definition and importance of organic farming

The industrial revolution was a turning point for agriculture, as factory-made implements designed to saving labour were widely diffused and artificial fertilizers were introduced (Grigg, 1984). Gradual increases in crop yield were due to the step-by-step replacement of human and animal labour with tractors and a wide range of machines, and also, to the chemical control of pests and diseases. However, the increasing use of synthetic chemicals in agriculture has had disadvantages, such as eutrophication and hypoxia (McIsaac et al., 2001), teratogenic effects on animals, health problems in humans and reduced populations of beneficial insects (Soule et al., 1990). Moreover, conventional agriculture also lacks sustainability because it heavily depends on petroleum for powering farm machinery, and for transporting products to markets that can be very far away from the farm (Pimentel and Pimentel, 1996).

Organic farming has arisen as an alternative to agriculture depending on chemicals. It is a method that has delivered improved productivity combined with consideration for quality of soil, environmental welfare, and human health. The key principles were self-sufficiency and economic viability, despite maintaining soil fertility through crop rotation and careful management and use of animal manures (Stockdale et al., 2001).

The area of organic land, the number of organic farmers and the organic market continued to grow. In Europe, 11.2 million hectares, constituting 2.3 percent of the agricultural area, were under organic management in 2012, an increase of 6% if compared with 2011. There were more than 320 000 producers. The value of the European organic market in 2012 was 22.8 billion euros and the overall growth rate was approximately six percent (FiBL-AMI-IFOAM, 2013). The European Department/Council of Agriculture estimates that the value of retail sales of MAP produced in organic farming in 2013 was approximately $6 billion (GPP, 2013). The number of organic farmers in EU has been increasing by about 12% per year (Carrera and González, 2011), most of them, small-scale producers.

While the per-hectare gross income from organic farming is less than that from conventional farming, the total benefit is higher. In fact, a 21-year study of biodynamic, bioorganic, and conventional farming systems in Central Europe found out that in the organic systems, crop yields were 20% lower, but fertilizer input was lower by 53% and pesticide input by 97% (Mäder et al., 2002). In this paper, MAP is considered as organic farming, focusing on the utilization of resources from the farm itself, excluding the use of synthetic fertilizers, pesticides, herbicides and growth regulators (Morujo, 2012).

Figure 1 produces a comparative analysis of the biggest organic markets.

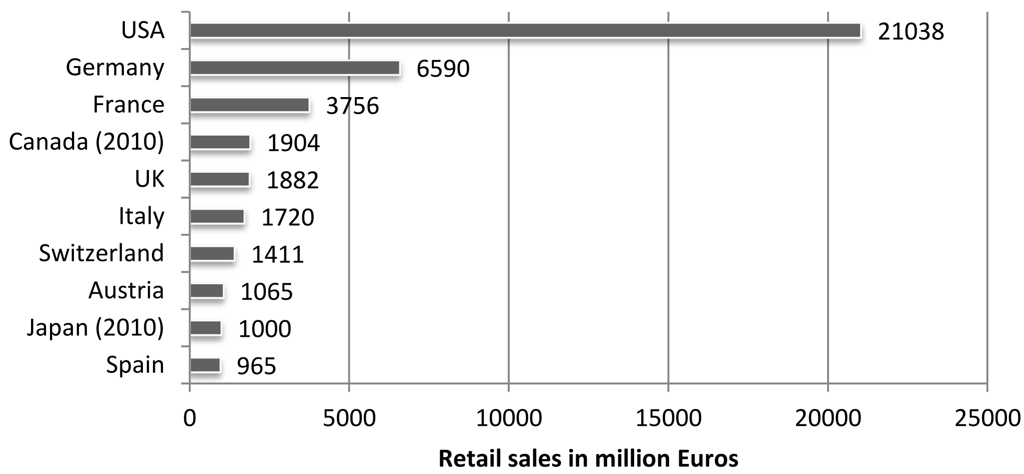

Figure 1. The largest organic markets. Source: FiBL – AMI-IFOAM (2013)

MAP importance in the world and in Portugal

Statistical information about MAP trading is neither abundant nor updated. According to some studies, the worldwide market for MAP worth about 60 000 million euros, and has a steady growth, which can vary between 3% and 12% per year (Gruenwald, 2010), depending on the market segment (Figure 2).

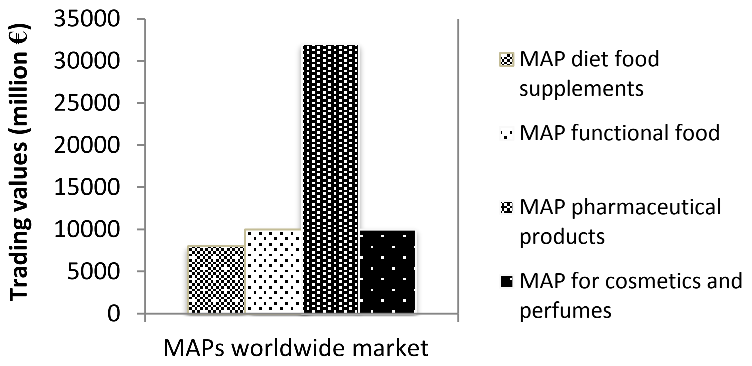

Figure 2. Figures for various segments of MAP. Source: Gruenwald (2010)

The exceptional conditions of Portugal, as regards soil and climate, could be a success story in the production of MAP since many of the big markets are dependent on imports. Thus, in economic terms, its production can provide good growth rates.

Portuguese flora comprises numerous MAP species, which show an exceptional potential for the development of sustainable explorations. Production in Portugal presents other advantages, such as: low labour costs and so, low harvest and processing costs; favourable edaphic and climatic conditions; and herbicide and chemical free production. However, despite all this potential, the development of the MAP sector is changing mainly due to the demand increase and to the interest of young farmers with high level of education. In fact, the *"Programa de Desenvolvimento Rural do Continente 2007-2014"*, ProDer, funded 240,61 hectars of projects from 257 young farmers (2008-2013, 1rst Quarter) (ProDer, 2014). Moreover, as depicted in Table 1, recent data shows that the MAP sector has risen significantly in Portugal. In fact, the explorations increased fourfold over the past four years (GPP, 2013) with significant growth expected to continue, and cultivated areas soared from 230 to 1324 ha in seven years.

Table 1. MAP Producers and MAP cultivated areas. Source: GPP (2013)

	2004	2005	2006	2007	2008	2009	2010	2011
Producers	27	37	51	54	50	70	173	197
Area (ha)	230	242	84	75	167	1625	1430	1324

The GPP (2013) study indicates that 197 MAP producer's croplands spread over each region of the country, being the largest area of production found in the coastal zone (Beira Litoral) (Figure 3).

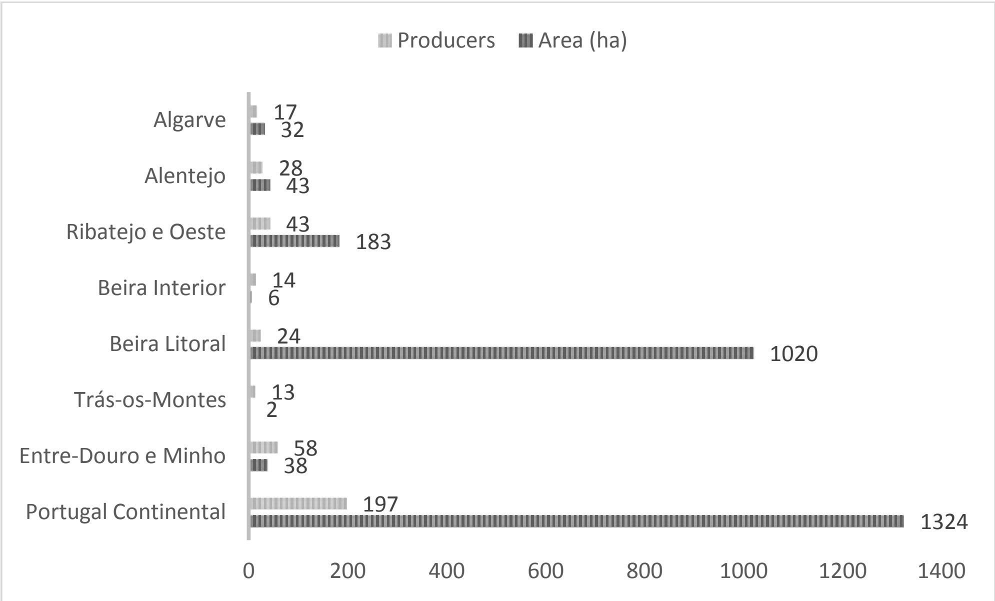

Figure 3. MAP Production Area (ha) and producers in Portuguese regions. Source: GPP (2013)

However, this increase in MAPs explorations, number of producers and outputs is not sufficient to ensure appropriate coverage of the broad range of the increasing market needs, as shown in Figure 4.

Main exporters and importers of MAP

Figure 4 depicts the MAP main exporter and importer countries according to the United Nations Commodity Trade Statistics Database for the years 2009-2012 (UN Comtrade, 2013).

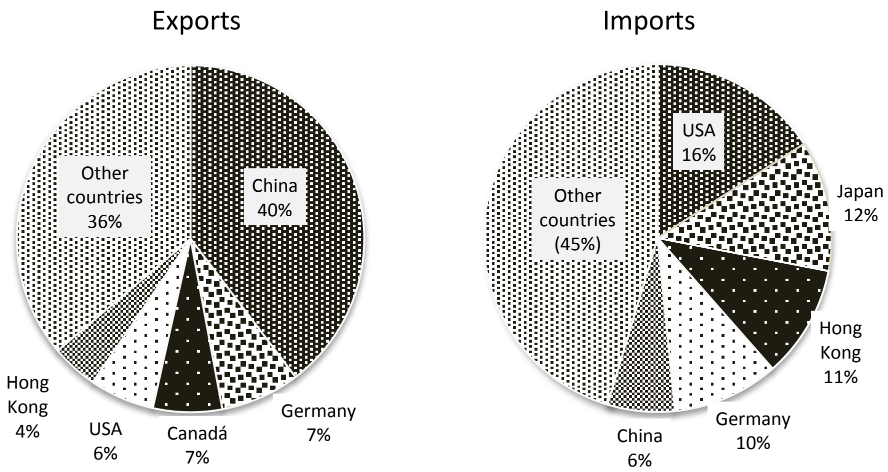

Figure 4. MAP exports and imports for the years 2009/2012. Source: UN Comtrade (2013)

3. Case Study

Methodology

This exploratory research proposal justifies a business policy for MAP supported by a collaborative operations network. So, it addresses the potential business interest of Medicinal and Aromatic Plants, by setting the scope of organic MAP and, it establishes the state of the art, by analysing the business requirements expressed by four panels of selected stakeholders. Finally, the resulting missing links are cross-examined within the context of the adequate knowledge areas.

Secondary data were used and generated by the participants in the four panels of the "National Forum – PAM Producers", venue: Oeiras, Portugal, 12th April 2013, which made a characterization of the MAP sector. Twelve people participated from Government (2), Rural Development Associations (5) and producers (5). The event was supported by the portuguese *Ministério do Ambiente, Ordenamento do Território e Energia*. The panels concerned the following topics: 1) Results of the EPAM project; 2) MAP production; 3) Markets; 4) Producers organization. The twelve participants were the Secretary of State, representatives of rural development associations and from the producers.

Characterization of the MAP sector

Next five subsections present the synthesis of this meeting concerning the MAP sector, in Portugal.

Market and competitive environment

The competitive environment was described as very unstable and as requiring a close relationship and monitoring. On the other hand, the market was defined by requiring a big sales effort, in a tough competitive environment, needing investor knowledge, which could be a problem for the new entrants. Visits to International Exhibitions, e.g. Biofach, were strongly advised. This could also help to track new market trends for gourmet products and, for plants on demand, e.g. stevia, as a non-caloric sweetener.

Pharmaceutical industry and health sector, perfumes and cosmetics, food, aromatherapy, phytotherapy, detergents and other chemical products were confirmed as the main applications and so, markets, of MAP. Europe, i.e. France and Germany were pointed out as a major destination, for bulk products sold in big bags. However, Japan and USA are addressed markets for essential oils and gourmet cans.

Prices were described as very volatile, while quantities kept varying, despite the same, as always, high requirements for quality. This places a threat to the traditional key success factors that assume high prices for high quality. In addition, the lack of tradition on recognizable brands appears to worsen things, as concerns essential oils and gourmet products. Other threats were shared, e.g. the requirement for tighter standards for health use, more demanding skills and specific equipments, in the short term.

New product development and R&D

The Secretary of State suggested to formalize R&D by a protocol led by the *Instituto Nacional de Investigação Agrária e Veterinária* (INIAV), the state laboratory responsible for research in agriculture and veterinary. ADCMoura and Animar should act as mediators among the farmers and INIAV. Both associations are non-profitable and target the sustainable development of rural regions.

Few initiatives of joint projects with universities were mentioned. The development of a new infusion and of new consumer habits involving the *Universidade do Porto* and other ProDer project concerning new own brands and product certification were quoted. Thus, no significant number of innovative projects is going on, despite the delegates recognition of the importance of R&D for new products and processes. Moreover, there were complaints about lack of institutional support. The Secretary of State still stressed the growing number of young and highly educated farmers entering the sector, as an opportunity to create more dynamic and innovative projects.

Nevertheless, it was mentioned that there is evidence of investment by foreign investors implementing greenhouses advanced technologies to foster productivity and to take advantage of the edafoclimatic conditions of Portugal. Finally, it was argued for the need to develop entrepreneurship both in the MAP sector and in its agents. ADCMoura provides an example of an initiative in this domain, to excluded people (ADCMoura, 2010).

<u>Collecting and treating data about the sector</u>

"Entrepreneurship in MAP" (EPAM) was mentioned as a successful initiative within the *Méditerranée Innovation Senteurs Saveurs* (MEDISS) project. It aims at divulgating MAP, by building up a data repository about georeferenced producers and by implementing several activities to animate the sector, e.g. conferences, panels, etc. Moreover, it was also argued that the EPAM site, which is visited by 4000 people per month, could act as a broker by distributing MAP products in medium/ long term.

Finally, the *Ministério da Agricultura e do Mar* divulgated the intention to release a study, in October 2013, to fully characterize the MAP investment in Portugal, by surveying the producers. The audience welcomed the initiative, despite it should be stressed the different nature of this information, when compared with the outcome of these panels, which included an important dimension of shared living experience. Thus, a detailed and reliable compilation of producer characterization, such as local, amount invested, average production, plants, public funding, producer age was expected (GPP, 2013).

<u>Production</u>

The concern with a fragmented production with many and small producers of which income provides just a weak economic sustainability was also mentioned. Some delegates did even argue for a need to link sales and agriculture. On the other hand, one of the most important worries regarded production costs. It was argued that costs are high because of: (i) manual operations; (ii) transportation cost for bulk products; (iii) underutilization of buildings and equipment; (iv) control difficulty; (v) no consistency in outputs; (vi) crop yield variation, specially in essential oils; (vii) imprecise capacity definition; (viii) small production volumes; (ix) not fully addressed need to adapt plant, machinery and techniques to the type of soil.

<u>The supply chain (?) appeal</u>

The "*fileira*" (supply chain?) emerged as a strong requirement to be developed and operationalised. There were many views on this issue, as follows: (i) it should be developed from the farmers (upstream focus); (ii) it should link consumers to producers (downstream focus); thus, waste should decrease and better stock control should arise; (iii) it should promote the intensification of partnerships and collaborative processes, as well as, people's relationships, education and training, getting funding, R&D effort, i.e. full networking fostering; (iv) it should develop the institutional perspective of sector organization in national/regional associations, no matter the juridical personality.

On the other hand, the great diversity among partners due to many small farmer structures was also recognized, as well as the need for an open environment favouring knowledge sharing between producers and, voluntary work. Some stakeholders believed that there was no critical mass, despite hoping this would improve in short term. Finally, there was a call for putting together an operational group for “Horizon 2020”.

An analysis of this very specific “selfie” of the MAP business is going to follow.

Results analysis

It was believed that Operations Management could have a unique contribution to this situation (Almeida et al., 2014). By Operations it was understood a holistic approach to the business greatest purpose, without discriminating the main typical business functions, i.e. R&D, marketing, production and finance. Therefore, three core missing links of the Business Policy are revisited, as follows:

<u>First missing link</u>

One identified missing link concerned the “*fileira*” concept that all delegates to the panel were able to spot, despite their different views on it. Thus, “*fileira*” was characterised like something that one expects to materialize in a tangible and stable relationship, solving most of the misunderstandings of the MAP business and appearing to require administrative regulation by the State.

Nevertheless, the proposed conceptual Operations Model by Almeida et al. (2014) works in a completely different way. In fact, in the MAP business, one company handling all the market issues to adapt in the competitive context was found out as hard and expensive. Therefore, it was suggested to pay more attention to the areas of inter-organizational co-operation, and to invest in more flexible logistics processes and supply chain (SC) networks, supported by information technologies (IT). The deployment of adequate IT systems could, then, push all the organizations involved, to collaborate and integrate temporary, to achieve momentary goals, based on shared core competencies, despite their dispersed geographical locations. So, it was proposed a Virtual Supply Chain model in which a variety of participants could dynamically cooperate, either to strategic or operational activities. The target was to share resources, risks and costs to create temporary co-operations to realize the value of short business opportunities that the partners could not address on their own.

The proposed conceptual model appears to addresses most of the specificities and requirements of the MAP business, through interactive collaboration, as follows: 1) it provides flexibility to adapt to unstable environments, enabling Collaborative Planning, Forecasting and Replenishment (CPFR); 2) it brings together all the agents of the supply chain from the brokers or even final customers to the producers and entrepreneurs, including rural development associations, funding partners, logistics service providers, certifiers, entrepreneurs, governmental agencies, universities and other R&D institutions; 3) it enables sharing core competencies within this partnership, despite being geographically dispersed; 4) it enables sharing physical resources, through common management at distance, reducing investment; 5) it enables shared services, e.g. training, maintenance, consultancy, etc.

<u>Second missing link</u>

The second missing link concerned the need to formalise the enlarged social platform of all the active agents – individual or organizations, private or public, business or non-profit, producers or customers – involved in the MAP business. This should be based on the civil society and built up on the top of the already established associations for rural development.

No need to create more institutions was found out. Moreover, divulgation, motivation and pure interest were gluing together all these agents. The recognised multilateral interest on the MAP cluster was considered as a cornerstone, despite individual initiatives were also welcome. Thus, this loose network of the MAP stakeholders, was put together, only, by non-mandatory interest, by understanding the need and the value of trust and collaboration, in order to build up a voluntary partnership. This was identified as the so-called "*fileira*" by Almeida et al. (2014).

Moreover, the SC agent – producer – was analysed. Several types of producers were defined, representing several SC agents with different needs, as follows: 1) small independent farmer; they do need to share resources and support to reach the market, producing on a small scale; 2) big independent farmer; they do have their own resources, producing on a larger scale; they do have dimension to go to the market on their own and to have their own R&D; 3) small dependent farmer; they just provide labour, usually they come from Employment Agencies and lack all other resources; 4) big dependent farmer; investors provide funding and they might also provide technology, in a franchising like model; they do not share resources.

The entrepreneur role was also addressed. In general, "Entrepreneurship is the process of identifying and starting a business venture, sourcing and organizing the required resources and taking both the risks and rewards associated with the venture." Therefore, as regards the resources, the entrepreneurs may own them or not, as long as they get access to them, which might also happen by a collaborative partnership. The important point is that entrepreneurs must create something innovative at a calculated risk that adds value for the society. It was concluded that it was not enough to be in the MAP business to automatically become an entrepreneur. This was a serious misconception that was being promoted, since farmers, businessman and entrepreneurs are different agents in their essence, despite their roles could mix once a while. To sum up, in the production domain several SC agents were identified with different roles and interests.

Third missing link

The third missing link was about the implementation of the social platform. The definition of a virtual platform was required, as well as its operationalisation. Nevertheless, one might not forget that there would be no virtual platform without the social one. This social momentum towards the MAP was found out as the most important issue, which was also identified as very time consuming and risky to create. Their mentors, promoters, pioneers and leaders were praised by their truly entrepreneurial initiative and by their perseverance to overcome so many obstacles during so many years. In summary, the social platform was found as the owner of the virtual one, which appeared to be a tool to operationalise the "*fileira*". Therefore, regulation, social interaction and the access typology were identified as key issues on this matter. Finally, it was found important to focus on specifying the functionalities of the technological platform based on the stakeholders requirements and, the design should favour a phased implementation. State of the art software, hardware and gadgets should be used to enable advanced updated features.

Missing links summary

A Virtual Supply Chain Model was proposed by Almeida et al. (2014), as a conceptual Operations Model to fulfil the needs of "*fileira*" and so, addressing the requirements expressed by a panel of experts for the MAP business. The existing social platform was branded as a truly entrepreneurial initiative requiring formalisation as a collaborative partnership. Moreover, several different types of partners were identified, as well as different producers were described. Finally, the need to operationalise a technological platform to support the conceptual model arose.

4. Discussion – building up a more robust conceptual basis

The ideas coming from the identified missing links in the results analysis of the case study are going to be cross-examined under a few current selected views of the related mentioned topics, in order to be developed a more robust conceptual basis. The objective is not to achieve an optimum solution, but to propose a relevant approach that might be just as valid as many others (Silva, 2009).

Firstly, the SC fundamentals are revisited confirming integration and co-ordination as the core mechanisms to design business processes supported by adequate Information and Communication Technology (ICT). Secondly, the competitive environment is reviewed providing support for the Business Policy considered in the first missing link. Thirdly, the factors to configure a network are introduced which operationalises the first part of the specification of collaborative processes, i.e. the second missing link concerning the need to formalise the enlarged social platform. Next, the third missing link is addressed in the subsection Technical Challenges of a Collaborative Network. Finally, the social platform and its social momentum were also modelled by considering the role of enterprise knowledge in collaborative ventures, as presented in the following subsections.

Revisiting the Supply Chain (SC) fundamentals: integration, co-ordination and ICT role

Organisations have been seeking to make the supply network more competitive as a whole. Therefore, models should attempt to integrate the different functions across the supply chain, which deal with the multidisciplinary problems of location/routing, production/distribution, supplier selection/inventory control, and scheduling/ transportation (Huang et al., 2009). Thus, the intertwined and overlapped co-ordination and integration mechanisms of the SC are recognised as fundamental to determine the impact of managerial levers on logistics processes across the entire supply network. Its understanding can help managers in the decision-making process to select the most appropriate action from a set of alternative solutions (Romano, 2003). Furthermore, integration mechanisms can also help managers to define to what extent such actions should pass through organisational boundaries, i.e. between functions and between companies. Romano (2003) also suggests the need for a cultural and attitudinal shift to address new ways of sharing risks and benefits between network members, in the long-term, by overcoming opportunistic individual behaviours. So, one might conclude that the above proposed CPFR approach appears to be aligned with an updated view of the phenomenon under study.

Hewitt (1992), Cooper et al., (1997) and Mabert and Venkataramanan (1998) are just some of the authors that have recognised integration as a fundamental principle of SCM, since it supports business processes across a supply network as being closely related with the effort to overcome intra- and inter-organisational boundaries. Moreover, Bechtel and Jayaram (1997) identify four dimensions of integration on SCM, namely, referring to internal and external functional integration, to the integration of logistics activities, to the integration of intra- and inter-company information flows and, to the integration of business processes across the supply network.

On the other hand, supply network co-ordination relates to planning, monitoring and aligning intra- and inter-organisational integrated logistics processes that extend from the market place, through the firm and its operations and beyond that to suppliers (e.g. Christopher, 1992;

Hewitt, 1994). Thus, materials, information, money and, even, ideas and people of the SC members flow, interact and require co-ordination. Moreover, a co-ordination mechanism is a pattern of decision making and communication among a set of actors who perform tasks to achieve goals (Malone, 1987) consisting (i) of the informational structure – who obtains what information from the environment, how is that information processed and then distributed among different members participating in the mechanism itself, and (ii) of the decision-making process helping to select the appropriate action that need to be performed from the set of alternative solutions (Marschak and Radner, 1972, in Romano, 2003).

Finally, Information and Communication Technology (ICT) has been considered as an important enabler of effective SCM, since that information holds the supply chain together (Kopczak, 1997; Simchi-Levi et al., 2000). Thus, ICT integration should be addressed because it not only facilitates information transfer between various companies and individuals in the network, but it also supports the shift from local to the whole network optimisation that the SCM asks for (Forza et al., 2000). In fact, the co-ordination mechanisms can be effectively activated (i) through the intensification of information exchanges, i.e. contacts, communication, opportunities alignment between the network members and, also, (ii) through the increase of visibility of each member on the whole network (Romano, 2003). Members of networks might include customers and suppliers, as well as, complementors and competitors. Interactions might consider other types of organisations, i.e. non-business (e.g. government agencies, laboratories, etc.), in addition to businesses (Ritter et al., 2004). In this way, all the mentioned stakeholders of MAP appear to be naturally included in the proposed solution.

One might argue that developing and managing intra- and inter-organisational business processes might be technologically simple, since most of the MAP firms are micro-enterprises and SMEs, i.e. of small size, with a few intermediate management levels, with no legacy systems, favouring centralisation in control and easing co-ordination. Perhaps the biggest barriers to overcome are of political, cultural and power nature, i.e. social, despite the scale of the problem still helping to set a solution.

Introducing virtual enterprises and networks: context, definition and positioning

The globalized nature of current business environments leads to the emergence of new networked enterprise organizational paradigms, e.g. supply chains, extended enterprises, virtual enterprises, collaborative networks, etc. (Ribeiro et al., 2012). Uncertainty, instability, turbulence and insecurity in the competitive environment, i.e. ever-changing markets, technology development, customer demands and global competition and decreases of product life cycles are key drivers of the demand for flexible, robust, autonomous, and responsive virtual enterprises (VE) linked together in a supply chain (Samdantsoodol, et al., 2012). Despite the challenges, a competitive and agile supply chain represents a unique opportunity for SMEs to tackle otherwise unreachable markets and opportunities concentrating their efforts on their core capabilities (Ribeiro et al., 2012) by leveraging collaboration, integration, intra- and inter-organizational networking, dynamic alliances, e-business through the Internet and ICT (Samdantsoodol, et al., 2012). Roche et. al. (1998) conclude that the main challenges in designing a virtual enterprise are (a) the fast reaction to customer demand; (b) the re-organization capability; (c) the communication between "incompatible" software and hardware systems (e.g. legacy systems, different IT sourcing, proprietary systems, etc); (d) the integration of heterogeneous entities; and (e) the knowledge exchanging and sharing.

To sum up, a virtual enterprise (VE) might be defined as a loose coalition both vertically and horizontally integrated in a temporary inter-organizational dynamic network with many different relationships based on trust that should be coordinated and aligned with the internal systems, and that might operationalise an alliance or a consortium of independent stakeholders, geographically dispersed, from which some might be in co-optition, to pursue a primarily temporary (that might also be permanent) breaking boundary co-operation driven by market and demand, sharing opportunities, information, cost, risk and technology, perhaps in projects required to adapt to change in order to address mostly short business opportunities, in fast changing market opportunities to realize value, by achieving more together, by focusing on distribution, on knowledge development and, on innovation explosion offering business opportunities and challenges. Moreover, workflow and information flows need to be controlled by well-defined decision-making process and coordination, to design an effective enterprise collaboration, based on sometimes peer-to-peer multi-agent systems, eventually, participating in other virtual enterprises and, enabled by IT, ICT software, Internet and mobile technologies, common communication protocols, object technology, application inter-operability, specification and exchange of standard information models, in order to magnify its core competencies, resources and skills with complementary ones (e.g. Samdantsoodol, et al., 2012).

Illustration of empirical interest of the concepts and models being proposed

The VE paradigm provides strong signals of fitting to the requirements of the MAP business because dispersed SME, unified by a collaborative network, based on trust, exchange and share and, supported by ICT, become stronger as regards common competences and resources. They can also get closer to the adequate supplying critical size, as well as to the required response/supplying needs, to address both a market and a competitive environment that are dynamic, uncertain and unstable.

One might quote the example of essential oils in the MAP business, as a requirement for cooperation, in order to achieve success. In fact, it is not technically and economically feasible for a SME to develop both effective and efficient technology to extract the oils on its own. On the other hand, at least two research projects one from a main State Labo (INETI) and another one from a big public university (Faculdade de Ciências), which have been forgotten “off line”, for a couple of years, have been identified in this investigation. These entities need to be captured to be part of a collaborative network. They also cannot pursue their research projects on themselves without being part of a broader formalised network of common interests.

Moreover, some crops need to be highly synchronised with the production process, in a very short gap of time, when the raw material for the oil is ready to be collected. This raises several types of operational problems, from logistics to production scale that also need to be fixed, within a collaborative environment. Despite some pilot collective initiatives to produce essential oils from ADCMoura are in progress, they look far from being satisfactory at an industrial scale.

Specification of collaborative processes

Network configuration factors

Configuration factors are necessary for describing and analysing collaborative networks. The factors *common goal* (which products?) and *relationship* (partnership) concern the strategy of the network. The *partners* (competencies, capacity, culture, motivation – learning, transferring of knowledge, improving competitiveness, etc. – objectives, localization, and roles) and the *organization* (high-level structure/topology; dependency or flow of resources between activities) concern the structure requirements. Finally, *duration* (short/long life, predefined or not) and *stability* (static/dynamic, same/new partners) concern the behaviour of the network. These characteristics allow us to understand both the collaboration type and, the goals and objectives of the network (Rajsiri, 2009).

Frayret et al. (2003) distinguish six possible relationships of inter-enterprise collaboration, including relationships between an enterprise and its customers, suppliers, competitors, service providers, complementary enterprises, as well as universities, which fit the situation of the MAP stakeholders well. In addition, two of the three groups suggested by Fombrun et al. (1982) also support the Frayret taxonomy and match the relationships among the MAP stakeholders, as follows: (i) on one hand, competition or horizontal relationship, concerning the collaboration between enterprises in the same business or industry, enable substitutability in terms of offers. The partners are currently competing for similar resources, or producing similar products, in order to increase negotiation power. The horizontal relationship relies on the strategic management domain; (ii) on the other hand, group interests or transversal relationships, concerning enterprises which are, neither substitutable, nor essentially interdependent, but add reciprocal value. The partners provide services that would be a benefit to each other. The partners establish their relationship in order to achieve the same interests, such as shared technology development.

The concept of topology might describe the structure of networks, as well as the duration, stability, and decision-making aspects. Burn et al. (1999) distinguished six different models of network. A few of them were selected because of its potential to fit to the MAP problem, as follows: (i) In star-alliance, some partners are dominant players, the leaders that supply competency and expertise to members (e.g. the different types of MAP producers); (ii) In value-alliances, participants may come together on a project basis co-ordinated by a general contractor; (iii) In market-alliances, organizations exist primarily in the cyberspace operating in the electronic market (potential alliance, based on cooperatives, similar to Mondragon (Mondragon Corporation, 2012, initially); (iv) Virtual brokers design dynamic networks prescribing strategic opportunities (virtual organization led by potentially emerging MAP brokers). Katzy et al. (2000) suggest the characterization of networks being based on three topologies: chain, star, and peer-to-peer. A peer-to-peer topology entails mutual relationships between all partners, which could be an adequate topology for some MAP situations. It is characterized by the lack of hierarchy where any peer may interact directly with any other peer. Their management is usually based on self-organization. The management competencies are distributed within the members and the decision making power is equal for every member. Such networks seem to be appropriate in industries where access to knowledge and expertise is of primary concern. However, establishing such networks requires careful selection of members, developing and enforcing strong codes of behaviour, as well as investing in building trust amongst each other.

In order to specify a MAP network, one have to make decisions about its configuration. Partners have to be carefully chosen and criteria must be set to match the desired relationships, as well as the network structure, among others. It might be possible to have different types of relationships and several co-existing virtual networks. For example, while one might be broker-led to meet commercial targets, the other one might be set on a peer-to-peer basis to share resources and develop competences. Examples from Mondragon (Mondragon Corporation, 2012) or from the moulds sector in Portugal are just an illustration of cases that could be approached in order to gather empirical knowledge at the business level to improve the accuracy of the characterization of the collaboration.

Technical challenges of a collaborative network

The ability to capture and share information between the information systems of different enterprises is very important, in order to set up a collaborative network of multi-enterprises, given the heterogeneities in culture, language, business, or technology. By definition, 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). Thus, relevant approaches for defining a knowledge-based system dedicated to the specification of collaborative processes will be pursued.

Interoperability can be seen as the capacity of enterprises to structure, formalize, and present their knowledge and know-how in order to be able to exchange or share it. In this case, interoperability is a crucial requirement for enterprises that need to be dynamically integrated. The problem of enterprise interoperability relies generally on three levels: data, resources and business processes (Rajsiri, 2009). This author made a proposal to capture knowledge from collaborative network partners, to develop a knowledge-based system, in order to specify collaborative process models, addressing the following questions: (i) What Knowledge on collaboration, where and how to capture it? (ii) How do we keep, store, represent and reuse existing collaboration knowledge? How do we derive new knowledge about collaborative processes from existing one? (iii) How and by which language do we describe, model and represent the collaborative process model?

Camarinha-Matos and Afsarmanesh (2006) refer to a collaborative network as being an alliance constituted of a variety of entities (e.g. organizations and people) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals, and whose interactions are supported by a computer network. This view both supports and summarises the above compiled definition.

Collaboration can be classified into four levels where each level extends the preceding one, as follows (Rajsiri, 2009): (i) Communication (data communication, exchange and share); (ii) Coordination (sharing and synchronization of tasks, i.e. applications, functions, and services available to partners); (iii) Cooperation (pursuing common goal, supported by the Enterprise Application Integration (EAI) or by the Service Oriented Architecture (SOA)); and, (iv) Integration: enterprises reunite (virtually) as one entity by means of interoperability, equivalent to the collaborative network level defined by Camarinha-Matos and Afsarmanesh (2006). Thus, two of the three technical challenges in the development of VE identified by Choy and Lee (2001) appear to be fully supported, as follows: (i) Development of the information infrastructure enabling to exchange data and business information seamlessly; (ii) Enhancement of design, planning methods and tools adapted for co-operative distributed networking enabling the accountability of the capabilities, capacity, availability and cost of the VE members. The third concern introduces the Development of Decision Support Systems (DSS) for partner selection, which has also already been recognized as a core issue (e.g. Katzy et al., 2000; Li et al., 2006; Samdantsoodol, et al., 2012). Therefore, it argued that one might specify the basic technical requirements for a collaborative network for MAP, since there is guidance to do so, there is a hierarchy of events and, many tasks appear to exhibit enough stability. However, some difficulties might arise with some of the most ill-defined tasks, perhaps occurring for non-routine situations.

Knowledge in a collaborative context

Knowledge is the most valuable asset of any enterprise for learning new things, solving problems, creating core competencies, and initiating new situations for both individuals and enterprises, both in the Present and in the Future (Liao, 2003). According to Kabilan (2007) knowledge is the appropriate collection of information. It describes what actions to take when certain information exists. It has to be useful. On the other hand, data is raw, it exists in any form, usable or not and it has no significance beyond its existence. Moreover, information is data that has been given meaning by way of a relational connection within a specific context. It can also be useful or not. Thus, knowledge is an active part in the process of transforming data into information (data interpretation), deriving new information from an existing one (elaboration) and acquiring new knowledge (learning) (Aamodt et al., 1995).

Nonaka (2007) made popular explicit and tacit knowledge, as well as their related transformations. Therefore, explicit knowledge is formal and systematic. For this reason, it can be easily communicated and shared. Tacit knowledge is not so easily expressible, is highly personal. It is hard to formalize and, therefore, difficult to communicate to others. Nevertheless, knowledge can mutate itself, as follows: (i) from tacit to tacit. Sometimes, one individual shares tacit knowledge directly with another (socialization); (ii) from explicit to explicit. An individual can also combine discrete pieces of explicit knowledge into a new whole (combination); (iii) from tacit to explicit. Converts tacit into explicit knowledge, allowing it to be shared with her project-development team (sharing); and, (iv) from explicit to tacit. As new explicit knowledge is shared throughout an organization, other employees begin to internalize it (internalisation). It is believed that, in the MAP business, all of these situations are found and that there is a continuous progress among most of these categories. Moreover, different categories require different formalization schemas, as well as different IT support.

On the other hand, Li et al. (2006) classifies enterprise knowledge relevant to the formation and operation of collaborative ventures into four categories: (i) enterprise core competence, regards the enterprise's own capabilities and capacities, strengths and weaknesses, and technical Intellectual Property Rights (IPR). This knowledge concerns the enterprise's internal experience which comes from formal and informal sources; (ii) VO (Virtual Organization) formation knowledge, regards best practice, critical factors, legal issues, risk analysis, and application of tools such as maturity gate planning in VO development. It also includes knowledge about collaboration and interoperability issues likely to be critical to partners. It comes from enterprise experience of current and previous collaboration; (iii) partner selection knowledge, regards core competencies, collaboration, interoperability capability and, reliability in collaboration of potential partners. It comes from knowledge of potential and actual partners from previous collaborations; and, (iv) VO operations management knowledge includes the VO enterprise model to support decision making, knowledge of interoperability issues concerning communication, and moderation knowledge about operational factors likely to be critical to partners. This looks as a nicely organised basis to start understanding, gathering and classifying, i.e. operationalising the knowledge required for a collaborative network in MAP.

Finally, according to Rajsiri (2009), the precision of collaboration characterization depends on the knowledge retrieved from partners. The capture of more and better quality knowledge leads to a more accurate characterization of the collaboration and the result will be closer to reality. So, it is absolutely critical that all the MAP partners are involved and participate in the process of expressing the knowledge requirements.

5. Conclusions

This paper reports a research concerning the domain of the Medicinal and Aromatic Plants (MAP). The analysis of the business context argued for organic MAP as being much more valued by the market. Organic MAP is a growing market with high rates of growth between 3 and 12% per year. Therefore, an opportunity in the international market was documented, which also pushed ahead expectations in Portugal that has got excellent edafoclimatic conditions for MAP. Moreover, a new generation of highly educated young farmers is returning to the rural world attracted by these opportunities, being supported by attractive government grants to help to establish themselves. Therefore, a relevant and opportune research question arose about the *adequateness and the refinement of a business policy supported by a collaborative operations virtual network within the scope of the Medicinal and Aromatic Plants (MAP) sector, in Portugal*.

This exploratory research proposal started to address its potential business interest, by setting the scope of organic MAP. Next, it established the state of the art, by analysing the business requirements expressed by four panels of selected stakeholders. Finally, the resulting missing links were examined within the scope of the adequate knowledge areas.

Data were collect from four panels in an event supported by the Secretary of State for Food and Agro-Food Research. Panel conclusions were treated, as follows: market; product development and R&D; organization of the sector data; production and supply chain. Three critical "missing links" were highlighted from the analysis of these data. First of all, "*fileira*" was conceptually modelled as a strong requirement for the development of a virtual supply chain, supported by a technological platform. Secondly, it was recognized the need for a broad social platform including all the MAP stakeholders before the technological development, which was classified as a true entrepreneurial event and, pioneers were praised for the initiative. Moreover, an important distinction between several categories of farmers was carried out, as well as a distinction between a farmer and an entrepreneur.

The proposals concerning the research question coming from the missing links were cross-examined, in order to be developed a more robust conceptual basis. Firstly, the SC fundamentals were revisited confirming integration and co-ordination as the core mechanisms to design and manage business processes across intra- and inter-organisational boundaries of a network to select right action supported by adequate Information and Communication Technology (ICT). Secondly, the competitive environment was reviewed suggesting the need for a virtual SC network as a significant Operations Model, which was also properly defined and placed into the context previously determined for MAP, providing support for the Business Policy introduced in the first missing link. Thirdly, the factors to configure a network were introduced and, some of them were approached more in-depth, e.g. the relationships or the network structures. Thus, the network configuration factors operationalised the first part of the specification of collaborative processes, which addressed the second missing link concerning the need to formalise the enlarged social platform. Next, the third missing link raised the point about the operationalisation of the social platform, which was addressed in the subsection Technical Challenges of a Collaborative Network. The social platform and its social momentum were also modelled by considering the definition and role of enterprise knowledge relevant to the formation and operation of collaborative ventures.

After this exercise, it is strongly believed that a collaborative operations network implemented by a technological platform that should be owned by the social platform, which is already established, is adequate to satisfy the needs of the so-called "fileira" within the current context of the MAP business, in Portugal. Thus, it appears to support an alternative relevant business policy, which is not evaluated as better than any other. Moreover, it is argued that the discussion, which was held, provides a significant basis to a credible, not ambiguous, effective approach to the specification of such an operations design because it provides supported guidance to address the research problem. To sum up, one might conclude, by arguing for Operations Management as a cornerstone to the mapping of the MAP sector together with the proposed co-evolution patterns between firms and with the dynamic capabilities that support the required transition, in order to target the creation and diffusion of adequate knowledge and so, to achieve sustainable competitive advantage. As a recommendation for further work it is believed that the expansion of the formulated principles might be easily turned into an inquiry tool to run an empirical test to a proposed solution.

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Towards a Theory of Industrial System: A Case study on Environmental Sustainability in the UK Medical Device Industry

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The purpose of this paper is to first develop an industrial system framework, by extending established structure and infrastructure definitions of the previous manufacturing systems to an industrial system level. This framework is tested by exploring the influence of environmental sustainability and dynamics on an industrial system involving the selected UK Medical Technology Sector Industrial System. The industrial system framework provides new insights into the structural and infrastructural components from operations management perspective. Analysis of the dynamics and environmental sustainability illustrated that external stakeholders have an indirect impact on the overall industrial system structure. In contrast, industrial actors were found to have direct and specific structural impact to a certain part of the value/supply chain, depending on the nature of the product-based systems. Furthermore, specific environmental challenges for the UK Medical Technology Sector Industrial System were highlighted. There is a need for a more effective infrastructure, incentivising industrial actors to adopt green methods as well as to share its knowledge through collaborations with its industrial system. This research turns contextual/business environmental elements of supply chains into more dominant elements of an operational system. The developed framework can be utilised by both external stakeholders and industrial actors in order to align its strategy with a certain industrial scale challenge.

NB: the full paper will be available online following the symposium

Understanding Emergent Industrial Ecosystems in Health Care

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Abstract
Health care systems face major challenges to meet the ever-increasing care demands and control of costs. In response there is a drive to demonstrate greater value, emergence of outcome-based payments and patient centric solutions. These have the potential to change health delivery and drive a convergence of medical and other technologies delivered through new business models and value chains. Future value chains therefore face greater uncertainty and influence from organisations and institutions not traditionally part of the industrial ecosystem. Understanding the emerging ecosystem landscape and the new capabilities required for success is critical for business strategy and investment decision making.

The focus of the research is to understand how organizations develop convergent technology products for the emerging health care industrial ecosystem, taking an integrative and modular approach to investigate the complexity of the health care industrial ecosystem, its business models and value networks.

Keywords: Convergence, Industrial Ecosystems, Business Models, Value Networks, Complex Systems.

Introduction

The challenges in delivering quality, affordable health care have been long debated (Herzlinger, 1978). Health care represents a significant part of the economy for many countries, typically representing between 6 and 17% of GDP (OECD, 2013, p. 157). Health systems around the globe face major challenges to meet the ever-increasing care demands and to control costs (Abbasi, McKinsey & Company, & World Economic Forum, 2013; Christensen, 2000; Herzlinger, 1978, 2000; Kim, Farmer, & Porter, 2013). Projections for the UK, based upon a review of several recent surveys conclude that health care spend as a percentage of GDP could rise from 7% to 10% by 2030 (Appleby, 2013, p. 43), similar rises are predicted for most major health care systems (see Figure 1). Consequently, most major economies are reviewing and transforming their health care systems (Abbasi et al., 2013).

The solutions have the potential to change health delivery, and to drive a greater convergence of medical and other technologies (Burns, 2012; Fish & White, 2014; Sharp et al., 2011). Convergence will not just occur in technology but will likely happen at every stage in the value chain (Eselius, Nimmagadda, Kambil, Hisey, & Rhodes, 2008). The changes identified have a consequential impact on the upstream value chain actors:

- An increasing move towards payment for outcomes, as opposed payment for product or service (Christensen et al., 2009; Porter, 2010b)
- A move to more patient centric treatment and care delivery services requiring increased personalisation and precision (Herzlinger, 2001; Shaller, 2007)
- Convergence of medical technologies to create value adding new products, to simplify and reduce cost in the providers' delivery value chain (Burns, 2012; Downey, 2008; Eselius et al., 2008; Fish & White, 2014). See Table 2 for current examples of convergence.

Sabatier *et al*. (2012) identified a number of '*new healthcare philosophies'* including personalized medicine, nanobiotechnology, theranostics and systems biology, all involving convergent technologies and '*incumbents from other sectors'*. Examples are included in Table 1.

Table 1 – Examples of Convergent and Combination Products

Combination and Convergence Product Themes	Examples
Pharmaceutical - Medical Device combination *(examples common)*	Pharmaceutical drug delivery device – e.g. inhaler, patch
Pharmaceutical - Diagnostic (and bioinformatics) complementary products *(small numbers marketed)*	Drug/Device combinations – companion diagnostics and therapeutic – not combined but complementary
Device, with drug coating *(early examples in development*)	Therapeutically active devices, DESs, coated hips
Device, Drug, Cell Therapy combinations *(in development)*	Soft Devices e.g. orthobiologics, BMP, artificial skin and scaffold
Drug and Device combination *(in development, early commercialisation)*	Drug/device combination – drug and in vivo monitoring e.g. Proteus device
Drug, plus Device plus ICT application *(in development)*	Drug and/or device and information – communication systems – 'telehealth' linked to drug delivery device and monitoring – for chronic condition COPD, motor degeneration

Sources: (Bangalore et al., 2013; Cheng, Koch, & Wu, 2012; FDA, 2014a; García Lizana, 2013; GBI Research, 2013; GlaxoSmithKline, 2012; M. W. Moore, Babu, & Cotter, 2012; Proteus, 2014; Puginier, 2009; Stryker, 2014; Tsimberidou, Eggermont, & Schilsky, 2014)

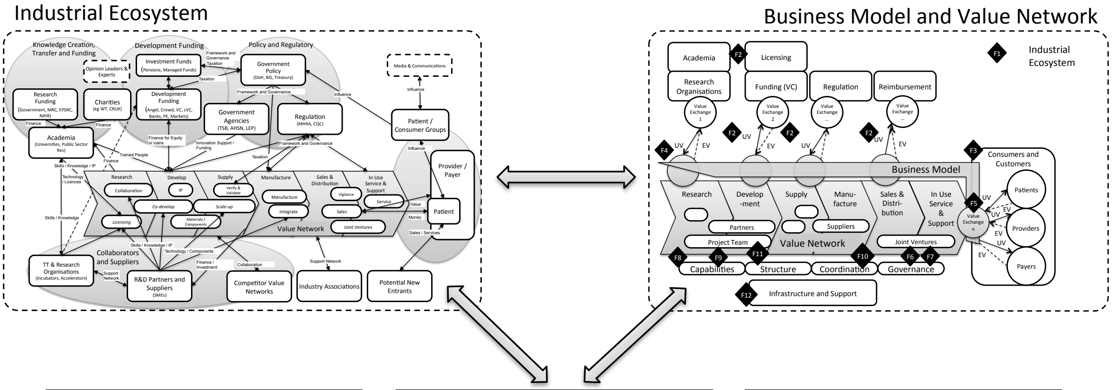
The industrial environment is made more complex as new alliance partners are likely to have divergent cultures, capabilities and perceptions, in terms of time, risk, investment, cost, and regulation (B. Mason, Bacher, Reynolds, & Fraser, 2013; Rikkiev & Mäkinen, 2013).

Research aims

The practice challenges stem from the rapidly changing industrial environment, the ability of 'producers' to identify, create, deliver and capture 'value' in the new environment. Emerging research question is thus:

- *How do organizations develop convergent technology products for the emerging health care industrial ecosystem?*

In addressing this a framework for convergent medical product development and a model will be developed that integrate the industrial ecosystem stakeholder and customer ‘value perspectives’ via a business model to the value network and required capabilities (see Figure 1).



	Strategic and Market Focus	
	Factor	**Example**
F1	**Ecosystem and Market understanding**	Firm undertakes activities to map and understand the ecosystem to keep pace with its evolution.
F2	**Stakeholder Management**	Map and engage stakeholders through the life-cycle of the development process to facilitate progress, and evolve relationships over time.
F3	**Customer Engagement**	Routines and capabilities to engage early in the development process with customers to inform product/service design and the potential business model options
F4	**Business Model development**	Map and understand the links between the business model and the required activities and capabilities.
F5	**Value Attributes**	Map and understand key value creation and capture steps (linked to business model)

	Senior Management Support	
	Factor	**Example**
F6	**Governance**	Active senior management support and engagement in investment decisions. Adequate knowledge for project selection and progression through objective decision gates.

	NPD Process	
	Factor	**Example**
F7	**Gate Criteria**	Objective Go / no go decision criteria to determine progressing to next phase, that consider external capabilities and paths.
F8	**Process**	A process or methodology exists to guide process development and quality management
F9	**Risk Management**	Risk management processes are in place to address patient and user safety risks, and the combination of technological risks, product integrations risks and business and commercial risks

	Organization and Team	
	Factor	**Example**
F10	**Alliance Partners**	Inter-organizational co-operation via clarity in objectives and scope. Accessing capabilities through alliance partners, adopting different alliance management approaches to different partners.
F11	**Project Team**	The core team has leadership, expertise and experience, and balances autonomy, accountability and empowerment within the governance framework
	Culture	
F12	**Support infrastructure**	Firm builds and makes use of ecosystem and infrastructure to complement capabilities and support development Culture

Capabilities Framework

Figure 1 – Exploratory Integrated Framework

Literature Review

The literature draws on industry and ecosystem evolution with a focus on industrial convergence, organizational capabilities (focussing on innovation and inter-organizational aspects), business models and value appropriation, underpinned by complex system and stakeholder theory.

Industry and Business Evolution

An emerging industry is often associated with disruptive technologies and business models (Probert, Ford, Routley, O’Sullivan, & Phaal, 2013). Thompson *et al*. (2001) defined an ‘emerging industry’ as one in its ‘*formative stage’* where firms face distinct challenges in addressing initial customer concerns, building capabilities, and developing a supportive infrastructure. Understanding the environment is an important step in any strategy formation process (M. Grant, 2010, p. 11; Porter, 1980, p. 3). Health systems and their ‘producers’ are similar to any other industry, but have additional complexity in terms of the customer structure, payers and intermediaries (Burns, 2012).

Industry changes are rooted in industrial evolution, a combination of incremental change (Marshall, 1921), punctuated with waves of ‘creative destruction’ (Schumpeter, 1928, 1939, 1947). Industrial evolution stems from two strands of theory: Industrial Organization, focussed on industry and structure, and Industrial Dynamics, focussed on individual firms and processes (Carlsson, 1987).

Industrial Organization, rooted in Chamberlin’s theory of monopolistic competition (1933) was a precursor to work by Mason (1957) and Bain (1959). Industrial Dynamics focussing on firms, and processes, which, according to Dahmén (1984), is more concerned with *transformation*, than growth. Building on Alchian’s (1950) initial concepts, Winter (1960) and later Nelson, proposed and subsequently developed an evolutionary approach to economics (Richard R Nelson, Winter, & Schuette, 1976; Richard R Nelson & Winter, 1974, 2002; Sidney G. Winter, 1984; Sidney G Winter, 1964) explaining evolution in terms of variation, selection, and retention. The concept of punctuated equilibrium (Richard R. Nelson, 1994), also drawn from biology (Eldredge & Gould, 1972; Gould, 1980) describes an alternative approach to gradualism. Nelson (1994) extended the evolutionary concept to address the coevolution of technology, firms, institutions and industry.

The role of technological innovation and change has been the source of much research (Devezas, 2005; Dosi, 1982, 1997; Malerba, Nelson, Orsenigo, & Winter, 1999; Richard R. Nelson, 1994; Romer, 1990; Tushman & Anderson, 1986). Tushman and Anderson (1986), concluded that breakthroughs, or technological discontinuities, significantly increases environmental uncertainty. Dosi (1982, 1997), borrowing from Kuhn's earlier work on scientific advances, proposed '*technological paradigms'* or '*technological trajectories'*, with relatively minor technological developments along a pattern, set by a paradigm. A related concept, the '*dominant design'*, further argues the importance of the technological evolution on an industry (Abernathy & Utterback, 1978; Murmann & Frenken, 2006; Suarez & Utterback, 1995; Utterback & Abernathy, 1975; Utterback & Suarez, 1993). There is therefore an expectation of a high degree of path dependence and as the technology matures, firms may also look downstream to diversify, but alternatively, it may result in a re-direction of effort (Fai & von Tunzelmann, 2001). Lubik *et al.* (2013, p. 23) identified two types of strategic orientation in emerging industries, 'market-pull' and 'technology push' concluding "*in contrast to much existing literature"* both technology-push firms and market-pull firms play key roles in the creation of new markets, and that often firms switched orientation as the business evolved.

Economic evolution is not just about the technology, "*As a first approximation, ... , firms may be expected to behave in the future according to the routines they have employed in the past*" (R R Nelson & Winter, 1982, p. 134); routines form the basis of organizational learning and capabilities. Abernathy and Clark (1985) defined innovation and evolution, in terms of technology, production, market or customer focus. The concept of disruptive innovations was re-popularised by Christensen (1997), exploring the impact of sustaining and disruptive change..

Disruptive innovations tend to come from small entrepreneurial firms (Christensen, 1997) and to survive in the evolving environment larger incumbent firms need to adapt (Anderson & Tushman, 1990; S.G. Winter, Kaniovski, & Dosi, 2000). However, the power of organizations to manage their routines may interfere with their ability to cope with the unexpected (Anderson & Tushman, 2001) therefore survival is linked to agility and "*dynamic capabilities*" (Easterby-Smith, Lyles, & Peteraf, 2009; Eisenhardt & Martin, 2000; Teece, 2007b). In economics, monopolistic firms develop innovative products as barriers to entry for competition (Markose, 2005b).

Drawing again from biology, in holobiont evolution it is not just the organism that evolves, but the associated microorganism community (Rosenberg, Koren, Reshef, Efrony, & Zilber-Rosenberg, 2007). The analogy in business is that it is not just the focal firm that evolves, but also the entire value network.

Ecosystem Structure and Relationships

The structural analysis of industries and industrial ecosystems has largely focussed on mature industries (Dicken, 2003; Porter, 1980). Moore (1993, 1996) describes ecosystem life cycles as stages, with evolving competition and cooperation. The lifecycle approach was further developed to identify activities needed to nurture its growth (Ka Rong, 2011; Ke Rong, Shi, & Yu, 2013; Ke Rong & Shi, 2009). Adamides (2009) identified a number of barriers to ecosystem development (2009, p. 175). Firms in an ecosystem may adopt different strategies: some seek to 'shape', some to 'follow' and some just 'reserve the right to play' (Hartigh & Asseldonk, 2004). In terms of structure Iansiti and Levien (2002, 2004) identified four types of ecosystem player: keystone, dominator, niche and the landlord.

Piepenbrock (2009) explored ecosystems and enterprise architectures, concluding that 'modular' enterprise architectures focus on top-line revenue growth, while the more successful 'integral' enterprise architectures focus on bottom-line profit growth and are exemplified by low numbers of high quality relationships. Hartigh (2004) also identified marginal economic gains beyond a critical network size.

Whilst the business literature discusses ecosystems widely, there is limited literature covering the approaches to understand and characterise the system. Taking a biological ecosystem approach, Muller (1992, 1997) identified a range of characteristics to define ecosystem structure, dynamics and relationships. An alternative approach by Peltoniemi (2006) takes a complexity and evolutionary economic view.

Ecosystem evolution: Technology and Industry Convergence

The term 'convergence' in relation to industries and technologies has been used for four decades (Fredrik Hacklin & Wallin, 2013), but multiple definitions exist for 'convergence' (Rikkiev & Mäkinen, 2013). Most prior research is in semiconductors, computing and communications technology, which saw waves of convergence in the 1990s and early 2000s (Bernabo et al., 2009b; Fredrik Hacklin & Wallin, 2013; Fredrik Hacklin, 2005; Stieglitz, 2003). There are limited studies in automotive (Bernabo et al., 2009a) and biotechnology (Bernabo et al., 2009c; Eselius et al., 2008; Shmulewitz, Langer, & Patton, 2006).

Intercompany collaboration is one of the primary strategies (Bores, Saurina, & Torres, 2003) with most innovation happening at the boundaries between disciplines (Fredrik Hacklin & Wallin, 2013), as exemplified by Apple (iPhone integrating mobile and software technologies) and BMW (integrating automotive and information technologies). Rim et al (2009) explored convergence between media and telecommunications, which resulted in '*rebundling*' value chains to create a '*composite business model'*.

Incremental innovations in one industry, that cross industry boundaries, can create disruptive innovations in the others (Fredrik Hacklin, 2005) through four different stages: (1) 'knowledge convergence', (2) 'technological convergence', (3) 'applicational convergence', and (4) 'industrial convergence' (2010). Choi (2001) defined industry convergence as "*blurred boundaries between industries by converging value propositions, technologies and markets*". Technology convergence itself can be classified as either 'substitution' or 'complementarity' (Stieglitz, 2003), from this Rikkiev *et al.* (2013) considered convergence in either the product or technology focussed, defining four convergence types (see Table 2).

Table 2 – Types of Industry Convergence (from Rikkiev)

	Substitution	Complementarity
Technology-based convergence	Technology substitution	Technology integration
Product-based convergence	Product substitution	Product complementarity

Using this the Convergent Medical Technologies in the Health Care industrial ecosystem can be classified as '**technology-based convergence'** and therefore likely to be '**complementarity**' in nature, leading to a '**technology integration' paradigm**, "*combining of new or existing technologies previously associated with different established industries into a new product, process or service*" (Rikkiev & Mäkinen, 2013). In this paradigm making correct choices amongst many technologies is important, together with a strong ability to integrate those technologies (Iansiti & West, 1997).

Taking a 'social' perspective, a company's human and financial capital, the impact of entrepreneurship, the network patterns on a cluster's configuration, and thus the location can have an impact on convergence (Phillips & Su, 2009). Different alliances need different capabilities as different types of partners connect (Rikkiev & Mäkinen, 2013; Rothaermel & Deeds, 2006), the size and capability of SMEs in the alliance is another potential factor (Dickson, Weaver, & Hoy, 2006). Hacklin et al (2013), identified the 'disciplinary distance' between a firm's own knowledge and other integration knowledge as key, and that the integration challenge lies mainly in individual or group-level learning.

Rikkiev and Mäkinen (2013) identified convergence as a 'complex' phenomenon and that it was difficult to bind all factors in a single study; they identified common themes in literature (Rikkiev & Mäkinen, 2013, p. 10) clustered under headings of company strategy, management, process, people and offering; concluding that convergence reshapes existing industry value networks and, "*by using innovative business models and alliances, companies can find profitable positions or niche in new industry value chain*".

Traditional, neoclassical, economic theories on alliances draw upon transaction cost economics to determine firm boundaries (Williamson, 1985b), but convergence requires not only efficiency and transaction cost considerations, it also impacts complementary assets to advance and commercialise new technologies (Rikkiev & Mäkinen, 2013). A resource based approach (J. Barney, 1991; R.M. Grant, 1996; Penrose, 1996; Prahalad & Hamel, 1990; Teece, Pisano, & Shuen, 1997), building on a knowledge and capability perspective, identifies collaboration as essential to gain access to external resources, and as such, provides a stronger basis to consider convergence. The success of each actor or member is "*influenced by the business ecosystem"*, as *"a holistic, intertwined entity that is in continuous evolution*" (Iansiti & Levien, 2004). Thus pointing to a need to address the ecosystem, business models and value networks *as a whole* to understand the implications for investment decisions and organizational capabilities.

Systems Approach and Understanding

Literature on industrial systems, business 'ecosystems', business models and recent literature on value chains and value networks have described them as '*systems*', yet these studies appear, with a few notable exceptions (Hartigh, Tol, Visscher, & Zhao, 2005; Marin, Stalker, & Mehandjiev, 2007; Peltoniemi & Vuori, 2004), to have a paucity of any recognisable ‘systems’ approaches.

Systems Overview

The roots of systems thinking and theory are complex (Jackson, 2000; Von Bertallanffy, 1968), drawing from mathematics, biology, physics, engineering, cybernetics and information theory, social sciences and philosophy (Boulding, 1956; Daellenbach & McNickle, 2005). Its application to business issues has had a varied history (Jackson, 2000). The early popularity and influence of ‘general systems theory’ from the 1950s to 1970s, resulted in general agreement of concepts such as ‘system’, ‘elements’, ‘relationships’, ‘boundary’, ‘emergence’, ‘hierarchy’, however during the 1970s and 1980s increasing criticism of the traditional approaches led to fundamental differences in orientation, largely driven by philosophical and methodological issues (Jackson, 2000, p. 3). In the 1990s, the popularity of Senge’s (1990) *The Fifth Discipline* and the ‘translation’ from biology of Maturana and Vela’s (1980) work on autopoesis popularized complexity and chaos theory (Gleick, 1987), resurrecting more mainstream interest. Mingers (1997), taking a multi-methodology approach and Taket and White (1997) using a ‘framework’, rather than a methodology, have attempted to overcome the methodological challenges.

A number of authors (Anderson, 1999; Luhmann, 2013; Midgley, 2003a; Von Bertallanffy, 1968) define the main features of complex systems; comprehensive reviews are provided by both Midgley (Midgley, 2003a, 2003b, 2003c, 2003d) and Francois (Francois, 2004).

Application of complex systems approaches in practice

Complex systems approaches have been used to study organizational dynamics (Dooley & Van de Ven, 1999; Lissack, 1999; Morel & Ramanujam, 1999; Newman, 2003) and strategy formulation (Levy, 1994).

The discipline of (social) network analysis or graph theory derives from many disciplines including mathematics, statistics, computer science, physics and sociology and has far-ranging applications in fields such as epidemiology and studies of online social networks, such as Facebook or Google+ (Knoke & Yang, 2008; Zimmerman, Lindberg, & Plesk, 1998).

Exploring *Chaos Theory*, Levy (1994) used a computer company supply chain as an example of a ‘*complex, dynamic, non-linear system’,* but adoption of complex systems approaches in supply chain theory has been slow. It was nearly twenty years later that Choi (2001) argued for a complex adaptive systems approach to supply network management. Despite another decade passing, use of ‘systems’ approaches in value chain and supply chain research has been relatively limited, with a small number of notable exceptions (Aelker, Bauernhansl, & Ehm, 2013; Behdani, 2012; T. Y. Choi & Dooley, 2009; T. Y. Choi & Hong, 2002; T. Y. Choi & Krause, 2006; He, Wang, & Cheng, 2013; Kumara, Ranjan, Surana, & Narayanan, 2003; Li, Ji, Sun, & Lee, 2009; Pathak, Day, Nair, Sawaya, & Kristal, 2007; Surana, Soundar, Greaves, & Raghavan, 2005).

McCarthy et al (2006) studied new product development as a non-linear, complex adaptive system, challenging the more linear approaches (Cooper, 1990, 2008), and identified that self-organization and emergence were particularly likely during the early stages; the discovery or ideation phase.

There are many different approaches to studying complex systems from systems dynamics (Forrester, 1993; Sterman, 2010) and modelling (Midgley, 2003b), to soft systems (Checkland & Scholes, 1990) to descriptive and philosophical approaches (Kenneth E. Boulding, 1987). The methodologies of Anderson (2005) and Westhorp (2012) have a number of similarities and are consistent with the multi-methodology advocated by Mingers (2006) and Midgely (2008). These can be synthesised into an approach that addresses the different structural, dynamic and relationship perspectives, which will be used in the later research.

Table 3 – Proposed methodology for Systems Investigation

Aspect	Methodology
Structural	Define the system, system boundaries, identify and map different system levels, hierarchies and sub-systems (modules) of relevance and key agents at the micro-, meso- and macro-levels
Dynamics	Understand the system history. Identify major inputs and outputs, key processes, patterns and trends, with particular attention on the unexpected or 'new'
Relationships	Understand the key interdependencies and relationships (e.g. contractual and governance) between agents, subsystems and between different system levels, with an emphasis on local causality, non-linearities and dimensions (e.g. scale and power)
Perspectives	Use different views and perspectives (both spatial and temporal) to broaden understanding, identify system changes and provide an opportunity for 'triangulation'.

Stakeholder theory

Stakeholder management is not a new field of inquiry, with origins traced to 'systems' work at SRI in the early 1960s (Freeman, 1984). However the application can be identified as early as the 1930s through the work of Professor E M Dodd with executives at General Electric (Preston & Sapienza, 1990, p. 362). Stakeholder theory is rooted in systems theory (Ackoff, 1974; Freeman & McVea, 2001).

Freeman's seminal work (1984) and later works (Freeman, Harrison, Wicks, Parmar, & De Colle, 2010; Freeman & McVea, 2001) provide a broad description of the theory, its implications and applications. Stakeholders are often defined as '*primary*' (including the immediate value chain from suppliers, through employees to customers) and '*secondary*' (which includes government, competitors, media and interest groups) (Freeman, 1984, p. 25). Mitchell and workers summarised the main formative literature and definitions of stakeholders (Mitchell, Agle, & Wood, 1997, pp. 860–862). A generally accepted definition is: "*an individual or group who can affect or is affected by the achievement of the organization's objectives*" (Freeman, 1984). Mitchell further proposes a typology or scoring system to categorise stakeholders based upon three attributes: 'power', 'legitimacy' and 'urgency' (1997, pp. 874–879).

Much stakeholder literature distinguishes between those who affect and who are affected by decision or action. This concept is summarised in the power (influence) and interest model (Ackermann & Eden, 2011, p. 183); now commonly used to segment stakeholder groups (Mainardes, Alves, & Raposo, 2012; Reed et al., 2009).

The nature of interdependence influences the stakeholders' strategies (Frooman, 1999, 2002), being determined by whether the network is unfamiliar or stable. Rowley

(1997) considers the nature (density) of the ecosystem network and the position of the focal firm (centrality) as influencing factors. Ackermann mapped interactions, a 'stakeholder management web' (2011, p. 189), to understand the needs of stakeholders and how these were met at three levels: rational (whole organization), process, and transactional. More recent approaches to stakeholder theory focus on the '*jointness*' of stakeholder interests rather than trade-offs (Freeman et al., 2010). Stakeholders themselves collaborate, leading to additional complexity (Savage et al., 2010).

Whilst stakeholders are often mentioned in value chain and business model literature, analysis rarely goes beyond the cursory; often only to acknowledge they exist (Baden-Fuller & Morgan, 2010; Fine & Simchi-Levi, 2010; Gardner & Cooper, 2003; Gereffi, 2011; Srai, 2007; Christoph Zott & Amit, 2010) and, as such, has not formed a significant component of recent business model or value network analysis. Recently, there has been some assessment of stakeholders, to the level of classification into 'primary' and 'secondary', but no further (Kumar, Srai, Pattinson, & Gregory, 2013; Srai & Harrington, n.d.). It is suggested that a better articulation of stakeholder influences, explicitly defining and mapping the relationships, may provide a more coherent link to the wider ecosystem and understand the required capabilities.

Organizational Capabilities

With roots in the work of Selznick (1948) and Penrose (1959), the Resource Based View (RBV) is essentially a learning, capabilities view of organisational growth. The first real reassessment of the work of Penrose, and acknowledged 'creator' of the RBV is Wernerfelt (1984) whose understated aim was to "*develop some simple economic tools for analysing a firm's resource position and to look at some strategic options suggested by this analysis*." Grant (1991) considered capabilities as organizational routines, i.e. more than just resources. Collis (1994) is more explicit, seeing capabilities as embedded in the firm's routines, and a product of the organization as an entire system (J. B. Barney, 1986; Dosi, Nelson, & Winter, 2010; R R Nelson & Winter, 1982). Amit and Schoemaker (1993) take a similar view, describing capabilities '*as a firm's capacity to deploy resources, usually in combination, using organizational processes, to effect a desired end*.'

The RBV holds that the key to a firm's competitive advantage is the possession of valuable, rare, inimitable, and non-substitutable (VRIN) capabilities (J. Barney, 1991; Eisenhardt & Martin, 2000) and confer competitive advantage to firms either through superior product or service offerings (Porter, 1996) or via production performance or efficiency (Womack, Jones, & Roos, 1990).

The concept of '*core competencies*' (Hamel, Doz, & Prahalad, 1989; Prahalad & Hamel, 1990), a revisiting of RBV, popularised such concepts within management, perceived easier for executives to consider, being controllable, unlike the external environment (Eisenhardt & Martin, 2000). '*Dynamic capabilities'* (Teece et al., 1997) contrast with ordinary or 'operational' capabilities (Sidney G. Winter, 2003). Teece, Pisano and Shuen (1997) identified dynamic capabilities as "*the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments"* (1997, p. 516). Subsequent authors have addressed questions such as: what constitutes such abilities, their attributes and where they come from? (Easterby-Smith et al., 2009; Eisenhardt & Martin, 2000; Helfat & Peteraf, 2003; Pandza & Thorpe, 2009; Teece, 2007a; Sidney G. Winter, 2003; Zollo & Winter, 2002).

It is not firms alone that compete (Gomes-Casseres, 1994), but alliances of firms in a network. Firms create alliances to address strategic needs and social opportunities (Eisenhardt & Schoonhoven, 1996), but despite their attractiveness alliances can have high transaction costs (Williamson, 1999), may present routes for 'leakage' of core competencies (Hamel et al., 1989) and may reduce profit or revenue streams (Eisenhardt & Schoonhoven, 1996). Alliances can fail due to poor partner selection (Hitt, Dacin, Levitas, Arregle, & Borza, 2000) or poor management (Ireland, 2002).

Firm structure, as previously noted, is also impacted by product modularity (C. Y. Baldwin & Clark, 1997). One can distinguish between decoupled, loosely coupled and tightly coupled systems (Brusoni, Prencipe, & Pavitt, 2001). Modularization reduces uncertainty and complexity helping to identify problem and solution paths, enhancing learning processes (Tyre & Hippel, 1997) and improving knowledge predictability (H. W. Chesbrough & Teece, 1996; Sanchez, 2002). Product modularization shapes the vertical division of labour, which favours knowledge specialization and creates boundaries (C. Baldwin & Clark, 2000; Langlois & Roberston, 1992; Sanchez & Mahoney, 1996; Schilling, 2000). Consequently, firms often align knowledge boundaries with production boundaries (Dibiaggio, 2007). Value chains fragment at those points where knowledge is *most explicit and codified*, which also determines the form of economic governance (Gereffi, Humphrey, & Sturgeon, 2005). Although activities can be divided between specialist firms, in convergence 'systems integrators' must develop knowledge outside the scope of their 'productive activities' (Patel & Pavitt, 1994) and integrate knowledge from different sources (Brusoni et al., 2001; Hobday, Davies, & Prencipe, 2005).

The concept of value network integration has been less explored; but Cacciatori (2005) noted that reintegration may occur when the limitations of specialization are reached and new customers services are demanded. Davies (Brady, Davies, & Gann, 2005; Davies, 2004) examined integration to provide high-value services to address customer-centric solutions, as may be required in health care.

Network Configuration and Structure

The concept that structure follows strategy (Chandler, 1962), was developed by Khandawalla (1970) to link planning capabilities with structure and later by Rumelt (1974), to link strategy to structure and performance. Structure or configuration have been described in various ways: Stabell (1998) identified three configurations (chain, shop and network), Miles and Snow (1978) suggest four basic configurations: defender, prospector, analyser and reactor. Mintzberg (1979) provided an alternative taxonomy using seven different forms. Structure is also linked to technology and technology diversification (N. S. Argyres, 1995; N. Argyres, 1996a, 1996b; Gruber, Heinemann, & Brettel, 2010) and can affect firm performance (Wasserman, 2008).

The broader development of firm capabilities and their link to configuration and structure results in a 'supply network configuration' (Srai, Gregory, & Shi, 2006; Srai & Gregory, 2005, 2008), extending the concept to global supply networks, using configuration maps, and linking these to capability maps, infers that there are "*particular advantages of different network configurations*". Further extensions of this mapping approach consider the broader value network within an ecosystem (Harrington, Baril, & Srai, 2012).

Investigating nascent and emergent industries, Srai and Harrington (n.d.), take the concept of network configuration, and combine it with ecosystem mapping, identifying: institutional players and secondary stakeholders, sector specialists and primary stakeholders, core products and supply chains, and the core firms as key features of the ecosystem. The approach is also used in related work (Srai et al., 2014), and whilst identifying the key actors and some ecosystem structure and macro-level dynamics, it does not appear to address the explicit micro- and meso-level nature of relationships between actors, particularly stakeholders, nor the value proposition.

Innovation and New Product Development

Approaches to NPD have been extensively reviewed (Browning & Ramasesh, 2009; Cooper & Kleinschmidt, 1995; Cooper, 2008) and identified various process model types used for NPD, variously described as: linear, “spiral”, concurrent, networked and ”vee”. It was noted that many processes focus on ‘actions’ rather than ‘interactions’ (Browning & Ramasesh, 2009). Handfield (2007) considers supplier integration into the NPD process, using a ‘typical’ process consisting of: idea generation, business and technical assessment, product (or process or service) concept development, product (or process or service) engineering and design, and prototype build, test, pilot and ramp-up for operations.

With ‘*open innovation’* (H. Chesbrough, 2006; Faems, 2008), the development decision gates require modified criteria (Gronlund, Sjodin, & Frishammar, 2010) to ensure external know-how, paths and capabilities are continually assessed. Convergent NPD could be considered an *extension* of the open innovation concept.

Investment decisions in situations with high uncertainty and risk carry a high risk of bias (and potential failure) as a consequence of *representativeness* (misconceptions, particularly where relationships are non-linear), *availability* (impacted by the ease of retrievability, and illusory correlations) and *adjustment and anchoring*, as a result of insufficient analysis and objectivity (Kahneman & Tversky, 2007; Kahnemann, Slovic, & Tversky, 1982). There is also a tendency to dismiss low probability, but highly impactful options (N. N. Taleb, 2007; N. T. Taleb, 2012). Influence of senior management on new product development processes, is important, primarily as ‘gate-keepers’ (Cooper & Kleinschmidt, 1995; Cooper, 1990, 2008) but can also influence in other ways (Gomes, de Weerd-Nederhof, Pearson, & Fisscher, 2001), more related to learning and knowledge management.

Successful projects have been considered in terms of project typology (Cooper & Kleinschmidt, 1995), in terms of required capabilities (Dvir, Lipovetsky, Shenhar, & Tishler, 1998) and concurrent product development (Haque, 2003) as required for CMT. Integrated product development (Gerwin & Barrowman, 2002) brings additional challenges for governance in senior management (Sommer et al., 2014). For complex innovative products, autonomous teams (Patanakul, Chen, & Lynn, 2012) with highly capable leaders and experienced team members (Sivasubramaniam, Liebowitz, & Lackman, 2012) have been found to be more effective.

In the health care industries there is a focus on product (and patient) risk framed by regulation and guidelines (FDA, 2014b, 2014d; Hulbert et al., 2008; ICH, 2005). Medicines and certain devices are assessed for risks and benefits before being used in patients, and undergo subsequent monitoring for adverse events. However, there are significant differences between these product groups in terms of the pattern of innovation and development, and the types of adverse events that arise from their use (Parvizi & Woods, 2014). In drug development a major focus is on identifying risk early to address late phase attrition (Roberts et al., 2014), the emphasis being on management of 'technical' risk.

New product development risk consist of technical, management and market risks (Hanpeng & Yongbo, 2011), determined by innovative and technological uncertainty, resource uncertainty, and consumer and competitive uncertainty (Moenaert & Souder, 1990) requiring mitigation (Kayis, Arndt, Zhou, & Amornsawadwatana, 2007). In convergent NPD additional management risks exist in achieving integration across alliance partners (Rikkiev & Mäkinen, 2013).

The ability to manage across these different risk types would therefore be expected to be a key capability in firms developing convergent medical technology products and services. The new product development factors, spanning organisation, leadership, process and capabilities are summarised in Table 4.

Table 4 - Factors in 'convergent' New Product Development

Factor	Example	Sources
Ecosystem and Market understanding	Firm undertakes activities to map and understand the ecosystem to keep pace with its evolution.	*(Fredrik Hacklin & Wallin, 2013; Fredrik Hacklin, 2005; Phaal, O'Sullivan, Routley, Ford, & Probert, 2011; Rikkiev & Mäkinen, 2013; Stieglitz, 2003)*
Stakeholder Management	Map and engage stakeholders through the life-cycle of the development process to facilitate progress, and evolve relationships over time.	*(Ackermann & Eden, 2011; Donaldson & Preston, 1995; Rowley, 1997)*
Governance	Active senior management support and engagement in investment decisions. Adequate knowledge for project selection and progression through objective decision gates.	*(Cooper, 1990, 2008; Rikkiev & Mäkinen, 2013; Salomo, Keinschmidt, & Brentani, 2010)*
Gate Criteria	Objective Go / no go decision criteria to determine progressing to next phase, that consider external capabilities and paths.	*(Cooper, 1990, 2008; Gronlund et al., 2010)*
Process	A process or methodology exists to guide process development and quality management	See Table 9
Risk Management	Risk management processes are in place to address patient and user safety risks, and the combination of technological risks, product integrations risks and business and commercial risks	*(Hanpeng & Yongbo, 2011; Hulbert et al., 2008; Kayis et al., 2007; McNeil, Frey, & Embrechts, 2010; Rikkiev & Mäkinen, 2013)*
Alliance Partners	Inter-organizational co-operation via clarity in objectives and scope. Accessing capabilities through alliance partners, adopting different alliance management approaches to different partners.	*(Dickson et al., 2006; Fredrik Hacklin & Wallin, 2013; Ireland, 2002; Lewrick et al., 2012; Rothaermel & Deeds, 2006; Soda, 2011)*
Project Team	The core team has leadership, expertise and experience, and balances autonomy, accountability and empowerment within the governance framework	*(Meyer, 1993; Patanakul et al., 2012; Sivasubramaniam et al., 2012)*
Support infrastructure	Firm builds and makes use of ecosystem and infrastructure to complement capabilities and support development	*(J. F. Moore, 2006; Peltoniemi & Vuori, 2004; Rikkiev & Mäkinen, 2013)*

A general problem with a 'capabilities approaches' however is, as noted by Bowman and Ambrosini (2000), that 'neo-classical' RBV approaches do not explain value creation and capture and this represents theoretical gap, requiring a business model or market view.

Business Models

In the past fifteen years, there has been growing interest in the 'business model' concept (Al-Debei & Avison, 2010). Interest accelerated with the advent of e-business, which required models that could not adequately be expressed by classical strategy and value chain models (Amit & Zott, 2001). Early research was in e-business (C. Zott, Amit, & Massa, 2011), however, the approaches are now more broadly accepted (DaSilva & Trkman, 2013; Johnson & Christensen, 2008; Osterwalder & Pigneur, 2013; Shafer, Smith, & Linder, 2005; C. Zott & Amit, 2013).

Definitions are ambiguous (DaSilva & Trkman, 2013), but in most studies business models are seen as an attempt to address the gap between strategy and execution, by recognising that conventional resource based views do not explicitly explain value creation and capture (Baden-Fuller, 2014). Business models have been seen: as a means to ensure sustainability and performance (Afuah & Tucci, 2000; Bocken, Short, Rana, & Evans, 2014; Funk, 2003), to define the important linkages between critical capabilities and business components, to ensure balanced resources (Achtenhagen, Melin, & Naldi, 2013), to describe "*as a system*" how a business fits together (Magretta, 2002) and identify the need for firms to have knowledge beyond their boundaries and current product offering (Brusoni et al., 2001).

Essentially, business model literature is split between seeing business models as *descriptors* of a business and its strategy, and those who see business models as a *model* of the business. As a consequence, there is no agreed taxonomy for business models.

Business Models as Descriptions

A significant body of the literature treats business models as 'descriptors' with the terms 'business model' and 'strategy' often used interchangeably. Others attempt to encompass all business activities into a single 'model' (H. W. Chesbrough, 2006; Johnson, Christensen, & Kagermann, 2008; Osterwalder & Pigneur, 2010; Petrovic, Kittl, & Teksten, 2001; Rajala & Westerlund, 2007). Chesbrough (2002; 2010) identifies six functions in a business model: the value proposition, the target market segment, revenue sources, the value chain and complementary assets, the position of the firm in the value network, the cost structure and profit potential. Presented as '*descriptions of the logic of the business system*', Petrovic et al (2001) divides a business into seven sub-elements, thereby attempting to encompass all of the business into a single 'model'.

Johnson and Christensen (2008) take a simpler approach, defining the business model as: Customer Value Proposition, a Profit Formula, the Key Resources and Key Processes, but extend the concept to describe supply chain and value chain activities.

Osterwalder and Pigneur (2010) developed a comprehensive framework that is viewed as a series of nine elements: value proposition, client relationships, client segments, distribution channels, partner network, key activities, key resources, and finally, cost structure and revenue flows. However, the model is somewhat limited in its treatment of the resource network and, again, duplicates existing value network concepts.

Business Models as Models

The concept of a business model as a 'model' has developed recently and Baden-Fuller (2010) provides a comprehensive summary of different models and, argued the explicit link with technological innovation as providing '*a more holistic view of a* *business model*' that is seen as a 'system' that defines customers, engaging with their needs, delivering satisfaction and monetizing value. In essence, the model defines a 'cause and effect' relationship (Baden-Fuller & Haefliger, 2013).

Teece (2010) sees business models as 'conceptual' rather than 'financial', but recognised that they create value, entice payments and convert payment to profits, by identifying choices. Further arguing that technological innovation alone does not guarantee commercial success and that a complementary business model is needed.

Zott and Amit have undertaken considerable research on business models (Amit & Zott, 2001, 2012; C. Zott et al., 2011; C. Zott & Amit, 2013; Christoph Zott & Amit, 2007, 2008, 2010), describing recent developments as a "*holistic-system level approach*" that is now theoretically anchored and addresses the challenge of unresolved overlaps with other theories, and can be used as a unit of analysis. Their model is described as an "*activity system"* with a set of interdependent organizational activities centred on the focal firm, using four 'design themes' to create value.

Richardson (2008) takes a more integrative approach using a wide range of literature to derive common elements that "*can be seen as the conceptual and architectural implementation of a business strategy and as the foundation for the implementation of business processes*". Using marketing-like approaches (Kapferer, 2004; Kotler, 2003) the model, aiming for "*a simplified logical structure",* is defined by: the value proposition, how value is created and then captured. These core elements are common themes in many models, however various authors elaborate adding elements, extending into capabilities or the value chain. Bocken *et al* (2014), explores sustainability, based upon Richardson's model (2008), addressing both technological and social perspectives.

The notion of a business model is that it represents '*an extension of the value chain idea*' (C. Zott & Amit, 2013). It has been argued that a business model is a standalone concept because it is a 'model' (Baden-Fuller & Haefliger, 2013) and the extent and complexity of that 'model' is a major strand of recent research (Andersson et al., 2006; C. Zott et al., 2011). Business models are not static, but evolve (Demil & Lecocq, 2010). However, Sosna (2010) identified that there is limited literature on model evolution.

Baden-Fuller and Morgan's model (2010), consists of: Customer Identification, Customer Engagement, Value Chain Linkages and Monetization. Combining the first two components, both considered marketing activities (Kapferer, 2004; Kotler, 2003) into a 'Value Proposition', the model is similar to Richardson's (2008).

Daellenbach (2005, pp. 87–88), based upon the work of Little (2004) proposed the following general criteria for a model: simple, complete, easy to manipulate, adaptive, appropriate for situation and relevant for decision making. Taking these characteristics into account, it is suggested that the business model should be simple, relevant and adaptive, not duplicate other models, but instead provide explicit linkages to established models, as depicted in Figure 2, in essence this is a modular concept that can be linked to other modular concepts.

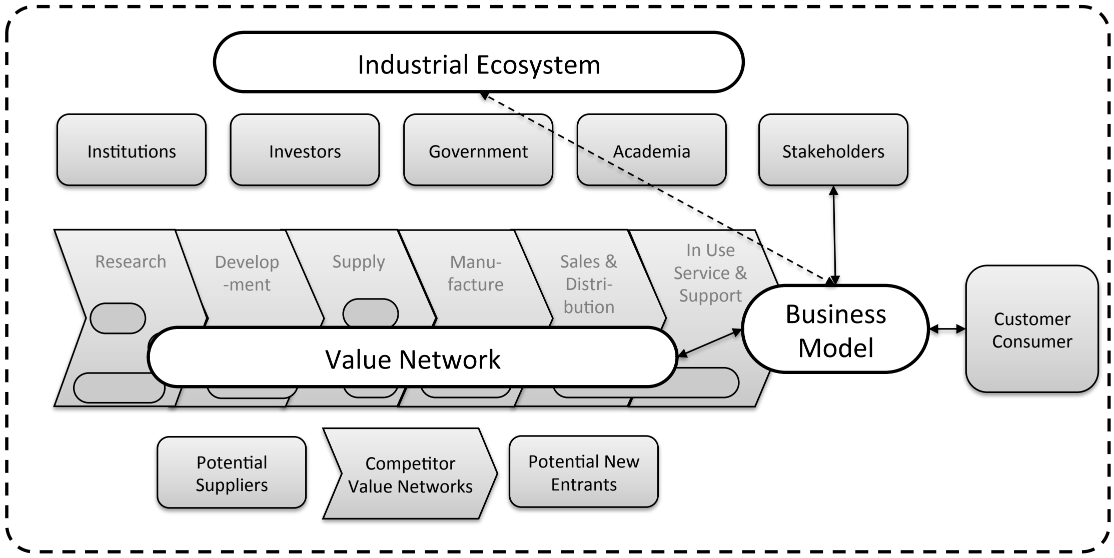


Figure 2 – Business Model linkage to Value Network model

Value, Creation and Capture

In the analysis of business models, the concept of 'value', its creation and capture are constant themes. Until recently there has been little agreement about what is 'value' (Bowman & Ambrosini, 2000, 2010; Lepak, Smith, & Taylor, 2007; Makadok & Coff, 2002; Priem, 2007). Bowman and Ambrosini (2010) suggested that a prime cause was that 'value' means different things to different people. To resolve this, 'value' has been defined (Bowman & Ambrosini, 2000; Lepak et al., 2007) in terms of 'value creation' and 'value capture' and between 'use value' (UV) and 'exchange value' (EV). The 'use value' can be considered akin to marketing's 'customer-perceived value' (CPV) (Kotler, 2003, pp. 418–426), which results from the prospective customer's evaluation of all benefits and costs of the offering or alternatives. Lepak (2007) introduced the concept of '*value slippage*', the difference between a firm's value creation and what it receives in capture. The 'slippage' being ascribed to the combined effect of competition and the countering '*isolating mechanism*', which provides knowledge, physical or legal barriers to prevent replication of the product or service. Importantly Lepak (2007) identifies that value creation and capture can occur and transfer across the hierarchy of society, organisation and individual, with utility in health care settings where benefits may be ascribed at different levels.

Teece (1986) linked 'who benefits' from innovation to the contractual conditions. This was extended beyond dyadic relations by Jacobides (2006), who developed route maps for value appropriation of asset combinations based upon the '*complementarity*' (which influences the 'size' of the value) and '*mobility*' (which influences the bargaining power).

Amit and Zott (2001) identify four sources of value creation in their e-business model, namely: efficiencies, complementarities, lock-in and novelty, which are conceptually similar to strategic value disciplines argued by Treacy and Wiersema (1997), and Hax and Wilde (1999).

Allee (2000, 2008), used a value network analysis to address intangible assets, identifying that they may be converted to monetary value or a negotiable form of value. During the development of a product, the asset is often intangible, until it can be 'converted' or 'enhanced' to 'recipient perceived value' or its wider 'societal value'. This offers a lifecycle approach, linking the business model and potential value proposition to key stakeholders in the ecosystem, and to the ultimate customers and consumers.

A schematic representation is provided in Figures 3 and 4. The approach addresses the potential and eventual value proposition in a value network context by suggesting that these propositions, can be thought of as the intersection of two or more (orthogonal) value chains: the producer's, other stakeholder's and the customer's or consumer's.

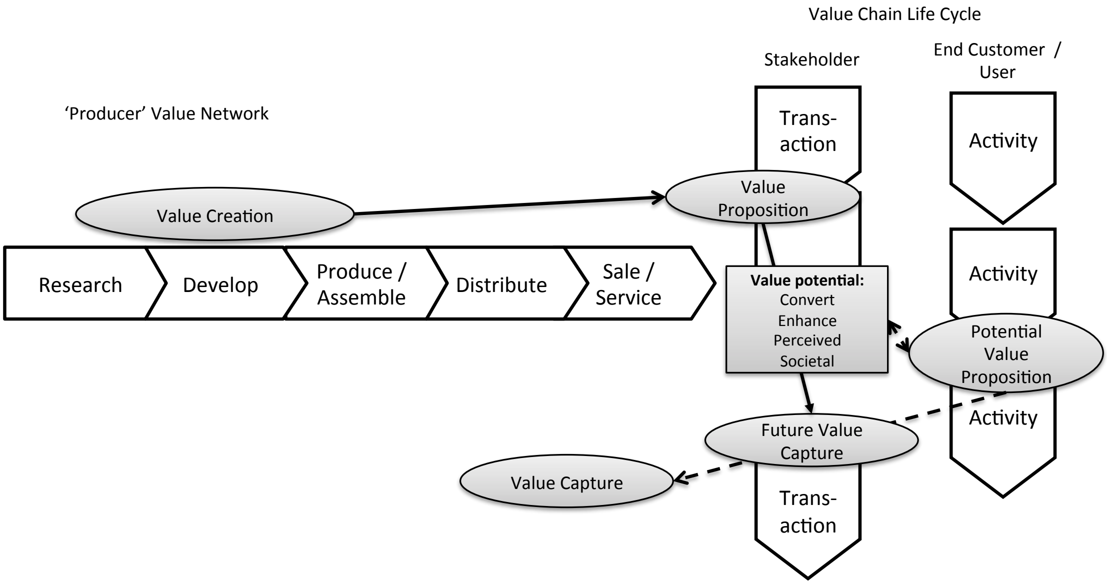


Figure 3 - Potential Value Proposition during development lifecycle

During the development phase (Figure 3) of a product or service, the '*potential*' value proposition is the dominant factor. During the life cycle there will be several such exchanges between the emerging value network and stakeholders such as knowledge providers, investors, and regulators. This environment is described as the '*value context*', the '*industrial landscape within which opportunities for creating and capturing value occur*', by Phaal et al (2011).

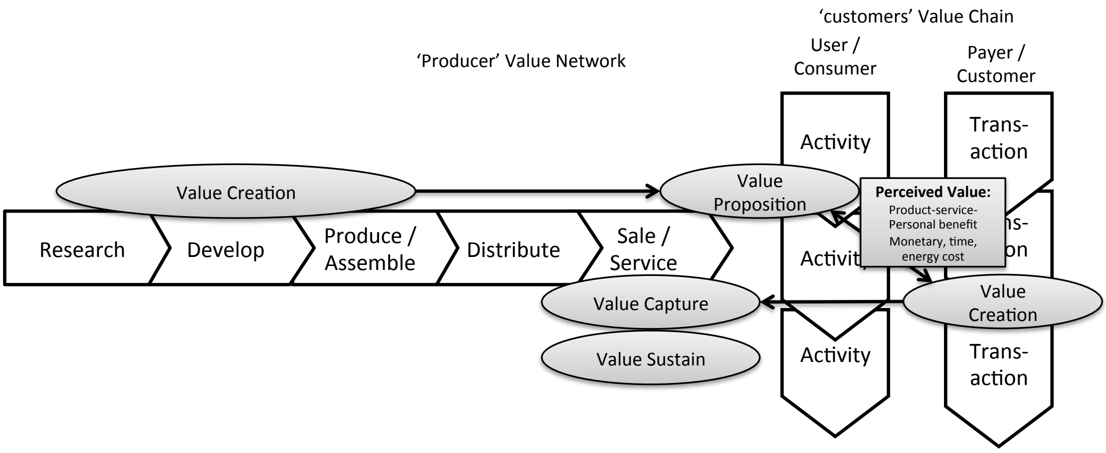


Figure 4 – Product-Service Value Exchange between Value Chains

For the actual product or service value proposition (Figure 4), the impact of a value proposition is to change the value chain (in terms of cost, performance or experience) for the customer and/or consumer, thereby creating value for them. In the transaction between these actors, the 'value exchange', provides the linking mechanism. Traditionally, this 'value exchange' has been seen as a dyadic relationship (Jacobides et al., 2006). In health care, economic evaluations are a common precursor to market access (Kobelt, 2013) and involve an analysis of outputs (benefits to patients and society) and inputs (costs and resource usage). In health care a triadic approach, or higher, may be necessary to explain the complex nature of the value exchange between a producer, and the patient, provider and payer.

This concept can then be extended to explicitly link the key actors in the industrial ecosystem, throughout the life cycle, with the business model and the value network, as shown in Figure 5. The link between these evolving value exchanges and the value network is the *evolving business model*.

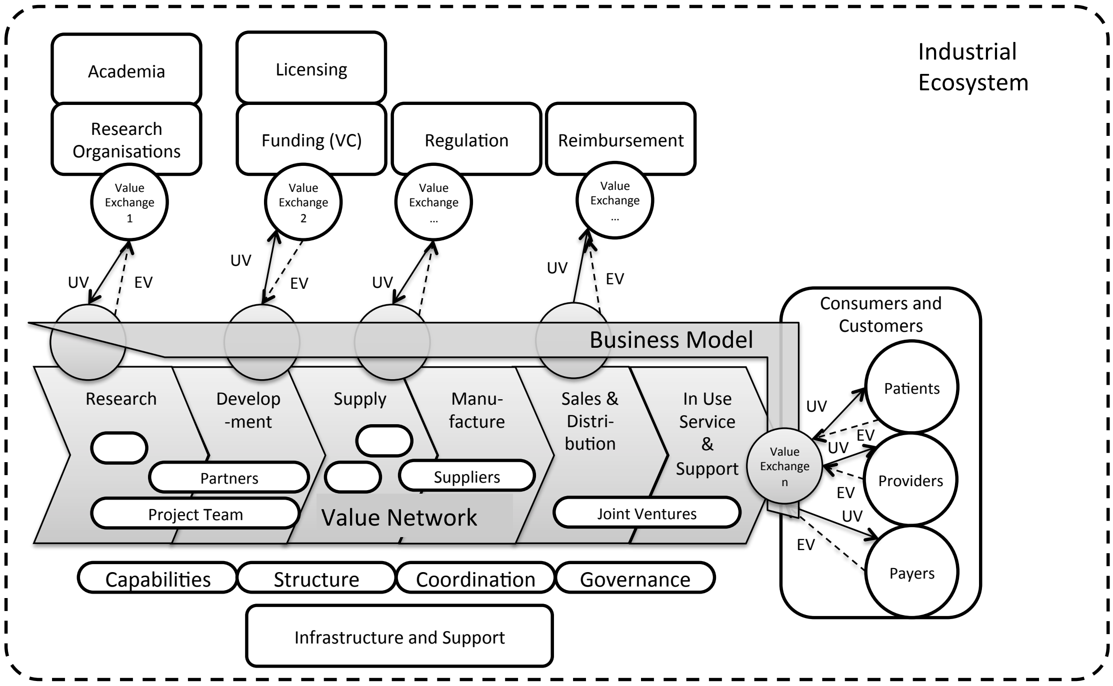


Figure 5 –Integrated Approach linking Ecosystem, Business Model and Value Network

This approach provides a mechanism to make *explicit* linkages between the customers and stakeholders in the ecosystems, identified as important in 'technology integration' convergence (Rikkiev & Mäkinen, 2013). These factors (see Table 5) can then be added to the preliminary factors in 'convergent' New Product Development from Table 4.

Table 5 - Customer and Business Model Factors

Factor	Example	Sources
Customer Engagement	Routines and capabilities to engage early in the development process with customers to inform product/service design and the potential business model options	(Baden-Fuller & Haefliger, 2013; Bowman & Ambrosini, 2010; Lepak et al., 2007; Rikkiev & Mäkinen, 2013)
Value Attributes	Map and understand the key Value Creation and Value Capture requirements	(Allee, 2008; Bowman & Ambrosini, 2010; Kotler, 2003; Lepak et al., 2007)
Business Model development	Map and understand the links between the business model and the required activities and capabilities.	(Allee, 2008; Baden-Fuller & Haefliger, 2013; Lepak et al., 2007; C. Zott & Amit, 2013)

The proposed framework and model provide a mechanism to *explicitly* link the activities of value creation and capture and the required capabilities in the value network, addressing the previously identified gaps in the literature.

Emerging Integrated Framework

The resulting preliminary frameworks are depicted in Figures 6 and 7 and Table 6.

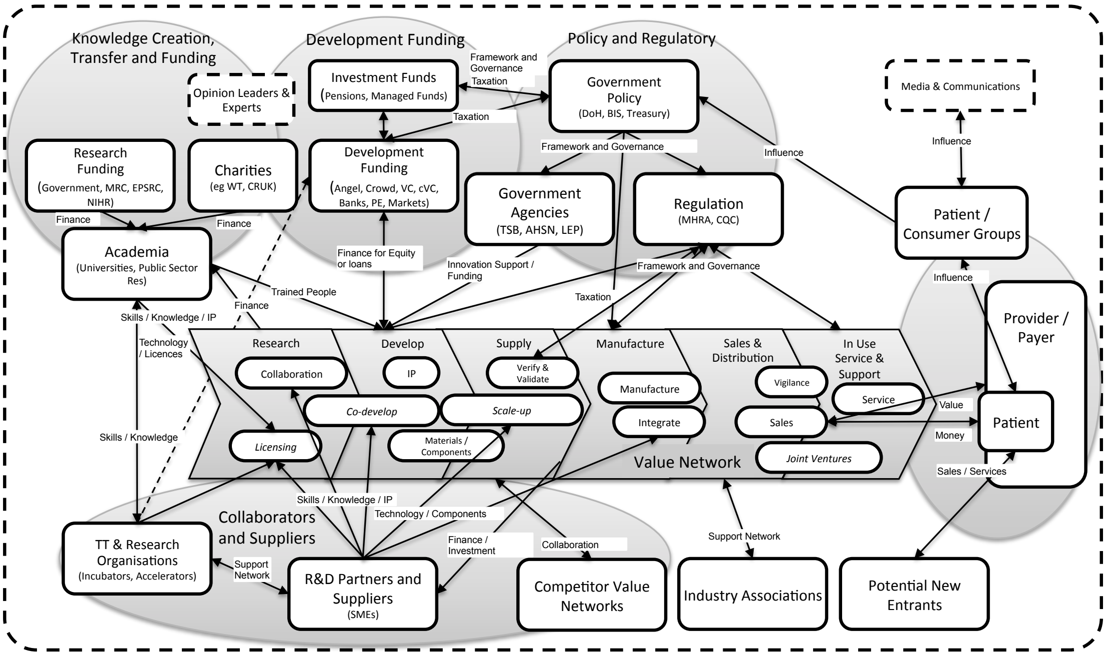


Figure 6 – Preliminary Industrial Ecosystem Framework

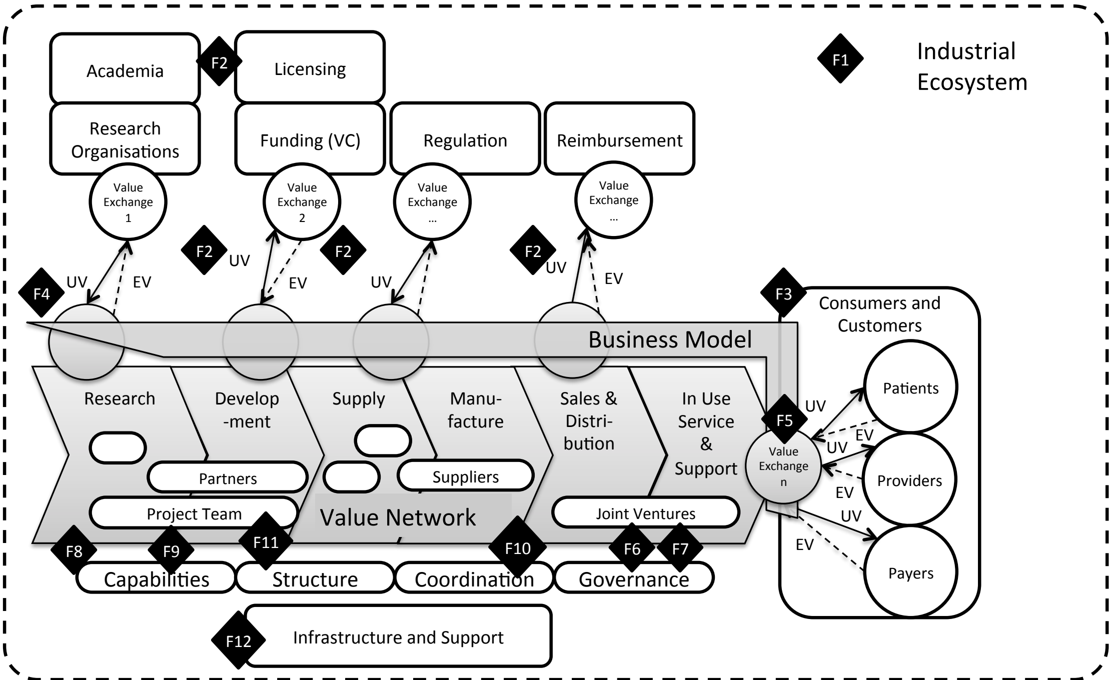


Figure 7 - Preliminary Framework to link IS to BM to VN

Table 6 – Preliminary Framework for Convergent NPD

	Factor	Example
	External / Market Interface	
F1	**Ecosystem and Market understanding**	Firm undertakes activities to map and understand the ecosystem to keep pace with its evolution.
F2	**Stakeholder Management**	Map and engage stakeholders through the life-cycle of the development process to facilitate progress, and evolve relationships over time.
F3	**Customer Engagement**	Routines and capabilities to engage early in the development process with customers to inform product/service design and the potential business model options
F4	**Business Model development**	Map and understand the links between the business model and the required activities and capabilities.
F5	**Value Attributes**	Map and understand key value creation and capture steps (linked to business model)
	Governance and Control	
F6	**Governance**	Active senior management support and engagement in investment decisions. Adequate knowledge for project selection and progression through objective decision gates.
F7	**Gate Criteria**	Objective Go / no go decision criteria to determine progressing to next phase, that consider external capabilities and paths.
	Capabilities	
F8	**Process**	A process or methodology exists to guide process development and quality management
F9	**Risk Management**	Risk management processes are in place to address patient and user safety risks, and the combination of technological risks, product integrations risks and business and commercial risks
F10	**Alliance Partners**	Inter-organizational co-operation via clarity in objectives and scope. Accessing capabilities through alliance partners, adopting different alliance management approaches to different partners.
F11	**Project Team**	The core team has leadership, expertise and experience, and balances autonomy, accountability and empowerment within the governance framework
F12	**Support infrastructure**	Firm builds and makes use of ecosystem and infrastructure to complement capabilities and support development

Together these provide an *integrated framework* to explain the ecosystem, business model and value network capability aspects for convergent medical product development.

Future Work

A number of preliminary case studies (2) and interviews (22) have been completed that support the proposed ecosystem challenges and the development of the model and framework. During the next phase of the research in-depth Case Studies will be conducted in organizations developing or supporting convergent medical product development to refine the framework.

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We do create and capture value, don't we?
A conceptual model of purchasing contribution to business performance.

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Abstract: A relevant question is holding court in academia: how does purchasing contribute to a company capability to create and capture value? This paper seeks to make two contributions. First, building on ambidexterity literature, we investigate how the purchasing function can simultaneously explore and exploit opportunities (i.e., purchasing ambidexterity), facilitating innovation while maintaining efficiency. Second, insights emerge from prior research and anecdotal evidence about the means by which purchasing ambidexterity can help the company to create and capture value. Two main outcomes of purchasing ambidexterity emerge which mediate the relationship with business performance: innovation and purchasing efficacy. This studies proposes a conceptual model and a set of propositions that future research can empirically validate. Finally, future research directions and managerial implications are discussed.

1. Introduction

"The new leaders in innovation will be those who figure out the best way to leverage a network of outsiders" (Pisano and Verganti, 2008). Purchasing managers are increasingly taking this advice seriously and, more and more, they focus on creating and capturing value through innovation with suppliers. The transformation of the role of the purchasing function from "efficiency seeking" to "innovation leading" can be even more central in today's high-velocity markets where industry structures are blurring and the company's resource base need to be continuously renewed. In line with this statement, a relevant question is holding court in academia: how does purchasing contribute to a company capability to create and capture value? (González-Benito, 2007; Krause et al., 2009; Priem and Swink, 2012).

Academics have tried to investigate the new role of purchasing. According to our review of the literature, the most of works focus on suppliers' potential for value creation (Möller and Törrönen, 2003; Ulaga, 2003; Walter et al., 2001). Other studies propose guidelines to maximize the value that can be created when working with suppliers at different stages of the relationship life cycle (Eggert et al., 2006). A third group of works focuses on mechanisms that would allow for a better integration between purchasing and other functions (Sheth et al., 2009). A fourth group of works focuses on supplier early involvement into New Product Development (NPD) (Schiele, 2010). Despite the effort spent by scholars, however, there is no clear and comprehensive theory on how purchasing can contribute to business performance, hence to creating and capturing value (González-Benito, 2007).

This paper seeks to make two contributions. First, building on ambidexterity literature, we investigate how the purchasing function can simultaneously explore and exploit (opportunities), facilitating innovation while maintaining efficiency. Purchasing ambidexterity can be seen as a dynamic capability (O'Reilly and Tushman, 2008): the ability of the purchasing function to simultaneously explore and exploit allows a firm to reconfigure assets and existing capabilities so to overcome the efficiency-innovation trade-off and maintain high business performance over time. So we aim to revise current literature on purchasing and supply management (PSM) through the theoretical lenses of ambidexterity. Second, insights emerge from prior research and anecdotal evidence about the means by which purchasing ambidexterity can help the company to create and capture value. Two main outcomes of purchasing ambidexterity emerge which mediate the relationship with business performance: innovation and purchasing efficacy.

The remainder of the paper is structured into three major sections. First, literature on value creation and capture is briefly summarized with a focus on preliminary definitions, ambidexterity and PSM literature. Next, a new, more nuanced, and multi-dimensional definition of purchasing ambidexterity is proposed. The third section presents a number of research propositions to explore potential competitive implications of purchasing ambidexterity.

2. Background

Literature background is structured so to provide a brief overview of the literature pertaining to 'value capture and creation', 'ambidexterity' and (PSM). By means of this literature review, we lay the foundation for a more detailed conceptual model and research propositions.

2.1. Value creation, value capture and business performance

Starting from the broadest possible perspective value creation involves increasing the subjective value that multiple stakeholders associate to the firm (Bititci et al., 2004; Bowman and Ambrosini, 2002; Walter et al., 2001). Here stakeholders include any group or individual who can affect or is affected by the achievement of an organization's objectives (Freeman, 1984). However more specific perspectives on value creation have been offered. From a shareholder perspective value creation corresponds to the creation of wealth (Bititci et al., 2004). In the case of customers, value is created when the firm is capable to increase the customers' perception of usefulness of its offer (Bowman and Ambrosini, 2002). Priem (2007) points out that, when value is created, the costumer “either (1) will be willing to pay more for a novel benefit, (2) will be willing to pay more for something perceived to be better, or (3) will chose to receive a previously available benefit at a lower unit cost, which often results in a greater volume purchased”. More broadly, value is created when a business acts in a way that generates positive externalities and increases the value stakeholders associate to its products and services.

Differently, value capture refers to the appropriation and retention of value by the firm (Bowman and Ambrosini, 2002). Value capture is usually determined by the bargain relationships between the firm and its stakeholders: the availability of close viable substitutes, combined with low switching costs, reduces a firm’s ability to capture value (Porter, 1985). As an innovation occurs, value is captured when the firm can appropriate for itself the innovation and leverage or access assets complementary (Jacobides et al., 2006; Teece, 2006). In other words, a firm benefits from the creation of value through the use of tacit knowledge, Intellectual Property Right or appropriate market entry timing and if it is well positioned to leverage the complementary assets needed to bring the innovation to the market.

In practical terms, value creation and value capture reflect business performance. Value creation is expected to lead to higher commercial performance (i.e., sales growth, reputation, customer experience, market share). Financial performance (i.e., return on investment, productivity and profit) is impacted only when the company is able to capture value.

2.2. From the industrial organization paradigm to ambidexterity

One of the first determinants of value creation and capture studied by the literature has been the industry structure and the strategic positioning of the firm within that structure (Porter, 1985). This approach, which roots in the industrial organization theory, emphasizes the actions a firm can take to create defensible positions against competitive forces. However, it has been shown that intra-industry differences in profits are greater than inter-industry differences, strongly suggesting the importance of firm-specific factors and the relative unimportance of industry effects.

To complement industrial organizational theory, the resource based view theory (RBV) focused on the internal organization of the firm. RBV assumes that firms can be conceptualized as bundles of resources. Such resources can be: physical (e.g., specialized equipment, geographic location, centralized production facilities) human (e.g., expertise, skills, experience), organizational (e.g., distinctive governance modes and informal structures; vertical lateral and horizontal boundaries and integration), financial (e.g., cash and liquidity) and reputational (e.g., intangible asset that shape the responses of customers, suppliers and competitors). Such resources are characterized by the so-called VRIN attributes (Valuable, Rare, Inimitable and Non-substitutable) and are seen as the real source of value (created and captured) (Barney, 1991). Eventually this view was expanded to consider firm’s capabilities that consist of cluster of resources, organizational routines and processes (Grant, 1991). The original definition of capabilities is built on the assumption that, once established, capabilities will be so difficult for rival organizations to imitate that they will provide competitive advantage in the long term. This may be true in a stable environment characterized by limited innovation and slow growth. In today’s globally competitive and constantly changing world, stability rarely exists for long and capabilities may be more easily overcome. To explain why and how companies that operate in dynamic environment create and capture value in a sustainable way, the RBV theory has been expanded to accommodate the concept of Dynamic Capabilities (DC). Dynamic capabilities are strategic routines by which managers purposefully alter their resource base to create new strategies that match and even create market change (Eisenhardt and Martin, 2000; Helfat et al., 2009; Teece et al., 1997). This dynamic view considers continuous improvement for short-term results as the unique way companies can create their temporary advantage. Developing effective dynamic capabilities allows company to perform better than competitors and to achieve and maintain a long-term leadership.

The concept of Dynamic Capabilities has been applied to supply chain. Dyer and Singh (1998) suggested that performance gains are possible when trading partners in the supply chain are willing to make relation-specific investments, develop knowledge-sharing routines and combine complementary resources in unique ways. This analysis suggests that a firm's critical resources may span over firm boundaries and may be embedded in inter-firm routines and processes. Building on this argument, Defee and Fugate (2010) suggests that dynamic capabilities may be extended beyond traditional single-firm view to exist across the relationships developed by multiple organizations in a supply chain. Therefore, in order to efficiently use the capabilities already existing among the supply chain players, firms should not replicate or internally develop the capabilities already available on the market but invest on new Dynamic Supply Chain Capabilities (DSCCs). While dynamic capabilities are firm centric, DSCCs are embedded within the collaborative routines formed between multiple supply chain players. Thus, multiple actors may jointly develop and use DSCCs to reenergize and update existing (static) capabilities or form entirely new capabilities shared in the supply chain.

Dynamic capabilites, either internal or shared within the supply chain, pertain to three different categories: (i) Knowledge accessing; (ii) co-evolving; (iii) knowledge managing. *Knowledge accessing* capabilities allow to scout and access opportunities (i.e., ideas, resources, capabilities and or solutions) outside of the company, or outside of the existing supply chain, but that can be exploited and leveraged by means of contracts or partnering initiatives (Lichtenthaler and Lichtenthaler, 2009). *Co-evolving* capabilities are conceptualized as used by a firm to connect webs of collaborations among multiple members of the supply chain for the purpose of generating new capabilities (Defee and Fugate, 2010). Finally, *Knowledge managing* are defined as a firm's ability to dynamically manage its knowledge base over time by reconfiguring and realigning the processes of knowledge exploration, retention, and exploitation inside and outside the organization (Lichtenthaler and Lichtenthaler, 2009).

According to recent literature, dynamic capabilities reflect into the firm's ability to both explore and exploit opportunities, which the literature refer to as *ambidexterity* (O'Reilly and Tushman, 2008; Raisch et al., 2009; Tushman and Reilly, 1996). The ability of the company to reconfigure the resource base to compete in emerging and mature business, to be ambidextrous, is a critical element to achieve and maintain high business performance. Ambidexterity or 'the ability to seize opportunities through the orchestration and integration of both new and existing resources to overcome inertia and path dependencies while creating and capturing value' is at the core of dynamic capabilities (He and Wong, 2004; O'Reilly and Tushman, 2008). Ambidextrous companies engage in exploration, which "is about search, discovery, autonomy, innovation and embracing variation" (O'Reilly and Tushman, 2008). They are also good at exploitation, which is about "efficiency, increasing productivity, control, certainty and variance reduction" (O'Reilly and Tushman, 2008). Ambidextrous firms excel into knowledge accessing, co-evolving and knowledge managing (O'Reilly and Tushman, 2008; Raisch et al., 2009; Tushman and Reilly, 1996). Knowledge accessing is enhanced since the ambidextrous firm develops a structured approach to scout new opportunities. Co-evolving is enabled because the ambidextrous firm develops a structured approach to exploit opportunities for the renewal of its organization and the supply chain. Having a better understanding of existing and exploitable opportunities, the ambidextrous firm is also best at managing knowledge and balancing (or reconnecting) exploration and exploitation activities.

Ambidexterity is attracting a great deal of attention in the supply chain management field. Recent published studies use ambidexterity theoretical lenses to explain performance differences among companies that confront dual demands of exploring new products/services/processes/business relationships and exploiting existing products/services/processes/business relationships (e.g., Blome et al., 2013; Chandrasekaran et al., 2012; Kristal et al., 2010). In this work we want to focus specifically on the role of the purchasing function and thus to understand how an ambidextrous purchasing function can contribute to a company's ability to create and capture value.

2.3. The role of purchasing in value creation and capture

The strategic importance of purchasing has been rising in last three decades. Porter's (1986) recognition that suppliers represent key elements for understanding competition served as initial trigger of a greater appreciation of purchasing as a strategic weapon (Ellram and Carr, 1994; Krause et al., 2001). Suppliers' potential value has been studied by many authors and described according to different functions, such as signaling (which refers to the possibility of accruing new markets through the reference impact of a particular supplier) innovation (which refer to the possibility of innovation with a particular supplier) and others (Möller and Rajala, 2007; Möller and Törrönen, 2003; Walter et al., 2001).

The literature, thus, has studied the way firms can assess (or explore) the value of their existing and potential suppliers. This has been recognized as demanding task for a number of reasons. First, the suppliers' value is often based on several organizational capabilities that are at least partly tacit and not easy to benchmark (Walter et al., 2001). Second, the suppliers' value may be dependent on the network of other relationships that this supplier and the buying firm have (Möller and Rajala, 2007). Also, suppliers' value may change during time and be different at different points of the relationship life cycle (Eggert et al., 2006). Last but not least, the suppliers' value is firm specific, since it has to be seen through the lenses of a firm's business strategy (González-Benito, 2007). For instance, a supplier has value only if the opportunities that lie behind them (i.e., ideas, resources, capabilities and solutions) allow the company to create value (i.e., matching specific stakeholder needs) and also to capture it (i.e., possibility of appropriation).

As an internal and external integrator with customers, suppliers, and third parties, purchasing personnel can be in the position to carry out many of the activities necessary to explore and exploit suppliers' value. On the one hand, purchasing can collect and analyze supply market data to scout innovation, screen technologies, develop raw materials trends and risk assessments (i.e., supply market intelligence) (Fugate et al., 2008; Handfield, 2010). However, the purchasing function needs to identify the functional competitive priorities that best support the firm business strategy and have a clear understanding of ideas, expectations, constraints and problems of internal and external stakeholders (e.g., customers, employees, etc.) without identified or immediate solutions (i.e., unmet needs). Thus, several authors have suggested that purchasing strategic integration with other functional units is both inevitable and beneficial to drive business

performance (Bals et al., 2009; Flynn et al., 2010; González-Benito, 2007; Piercy, 2009; Sheth et al., 2009).
On the other hand, the literature describes the involvement of the company into more exploitative activities. For instance, several studies have shed light on the positive effects that supplier early involvement in NPD have on a firm performance (Johnsen, 2009; Wagner, 2012). To support supplier integration, the purchasing function has been shown to assume a 'dual' role: contributing to NPD while also managing overall costs (Schiele, 2010). Blome et al. (2013) also suggest that the simultaneous pursuit of both relational and contractual governance elements in buyer-supplier relationships - i.e., ambidextrous governance - allows to better exploit suppliers' value, with effects on innovation and cost performance at the firm level. These works have thus addressed ambidexterity only with a somehow narrow focus on the governance of the relationship.

Although previous research on PSM recognizes the pivotal role purchasing functions might play for business performance, it tends to focus on specific and potentially disconnected purchasing practices, rather than on the purchasing capability to simultaneously conduct them. This challenge has been tackled in this research which applies ambidexterity to purchasing and proposes a model that shows how purchasing can widely contribute to a company ability to create and capture value, also going beyond the typical boundaries of the purchasing department.

3. Purchasing ambidexterity

Given the importance of suppliers and purchasing for business performance (e.g., González-Benito, 2007; Möller and Törrönen, 2003), the literature pertaining to PSM needs to evolve to formally recognize purchasing functions as a seeker and exploiter of opportunities (i.e., ideas, resources, capabilities and solutions) for innovation and efficiency. The idea here is to more comprehensively describe how purchasing becomes part of the solution generating process and becomes more involved in understanding and fulfilling stakeholders unmet needs, while keeping costs under control. The analysis of PSM literature according to the theoretical lenses of ambidexterity suggests that purchasing ambidexterity can be operationally defined by the involvement of the purchasing function into three processes: 'unmet needs exploration', 'supply opportunities exploration' and 'solution delivery'.

3.1. Unmet needs exploration

Expectations, constraints and problems of internal and external stakeholders (e.g., customers, organizational departments, etc.) without identified or immediate solutions can be seen as unmet needs. An important part of the value creation and capture process relates to the understanding and prioritization of such needs.

Unmet needs exploration, thus, refers to the institutionalization of a set of activities that are commonly adopted to identify, understand, prioritize and share unmet needs throughout the organization. This institutionalization typically includes market analysis (e.g., dynamics and trend), scenario analysis, and the adoption of methods such as voice of customer and lead user by multi-functional innovation teams.

The involvement of the purchasing function in these activities is important: in order to create and capture value, strategic external relationships (with customer, supplier and partners) should be mirrored in strategic internal relationships (between the functions which lead responsibilities for managing relationships with customers, supplier and partners) (Piercy, 2009) and triangulation of information from multiple parties must be ensured. In this sense, the involvement of the purchasing function in this process denotes its ability to identify the functional competitive priorities that best support the business strategy (González-Benito, 2007) and to work with existing and potential suppliers in a way that maximize their creative thinking, that prevents leakage of critical information, that has the opportunity to generate value for the business (Sheth et al., 2009).

3.2. Supply opportunities exploration

Supply opportunities refer to ideas, resources, capabilities and or solutions of existing or potential suppliers, which can be useful to create and capture value (e.g., Möller and Törrönen, 2003). Thus, *supply opportunities exploration* refers to the institutionalization of a set of activities that are commonly adopted to scout and assess such opportunities. This institutionalization includes innovation days or workshops with suppliers, roadmaps presentations with suppliers, industry meetings, participation in consortia and regional clusters and supply market intelligence with strong focus on potential substitutes (Handfield, 2010; Hult et al., 2004). These activities support strategic business decisions that lie outside the realm of contracting and category analysis, they can positively affect decisions in annual budgeting, customer markets, technology integration and financial budgeting.

Although there is a growing trend toward the use of external resources to explore supply opportunities (Handfield, 2010), the involvement of the purchasing function in this institutionalization denotes its ability to effectively find the right 'solutions' to address unmet needs. This is typically done for example by deciding whether to use existing suppliers operating into one or more purchase categories, or to look for new suppliers (Kraljic, 1983). To illustrate, BMW uses tools such as the active participation to regional clusters and the implementation of active workshops to discuss innovation with suppliers, so to proceed further in their selection and exploitation of supply opportunities. Planning, ensuring participation and conducing meetings fall to the purchasing function, which is responsible for preliminary selection, meetings preparation, meetings, tracking results and closing (Schiele, 2010, p. 148). In 2012, one of the challenge for Unilever was to find reformulation technologies which break down fatty deposits left on clothes and hard surfaces in eco-friendly ways. This challenge, together with ten others, was listed by the purchasing function on a portal open to some suppliers. This resulted in 1,000 submissions from suppliers. Jon Hague, VP Open Innovation at Unilever was "hugely impressed by the quality, ingenuity and inventiveness of the submissions" (Procurement Leaders Staff, 2012).

3.3. Solutions delivery

Purchasing can actively alter a firm resource base (i.e., acquire and shed new valuable resources, integrate them together and recombine them) in a way that allows the firm to create value for its stakeholders but also to capture part of this value (Defee and Fugate, 2010; Fugate et al., 2008; Handfield, 2010). In essence, *Solutions delivery* refers to the institutionalization of a set of activities that are commonly adopted to exploit the value that lies behind existing or potential suppliers, with concrete returns for the company and its stakeholders (i.e. value created and captured). Typically, it includes activities such as supplier qualification, development and integration (Flynn et al., 2010; Krause et al., 2007), co-design with suppliers (Johnsen, 2009;

Schiele, 2010), R&D outsourcing and the orchestration of collaborative initiatives between suppliers.

The involvement of the purchasing function in such exploitative activities denotes its ability to re-shape a firm's portfolio of resources (i.e., ideas, resources, capabilities and solutions) for the purpose of generating innovations and efficiencies. To illustrate, we might consider the recent attempt by Boeing to bring together an international team of suppliers and engineers from the United States, Japan, Italy, Australia, France and elsewhere to develop its new Jet. The stake was high, it meant nothing less than fully rethinking how a plane could be developed. Even if the outcomes were not as successful as it was expected on the Boeing side, this initiative has transformed how Boeing will deliver planes in the future and the role the purchasing function will play in this process (Peterson, 2011).

3.4. Toward an integrative view

A synthesis of the literature indicates that three underlying processes – unmet needs exploration, supply opportunities exploration and solutions delivery – collectively characterize purchasing ambidexterity or the ability of the purchasing function to simultaneously explore and exploit (opportunities), which contributes to a firm's ability to overcome the efficiency-innovation trade-off and maintain high business performance over time. The three underlying processes are presented in Table 1, which also shows the practical contribution the purchasing function brings in each of these.

Table 1. The role of an ambidextrous purchasing function into value creation and capture processes

Value creation and capture processes	*Definition*	*Contributions brought by the purchasing function*
Unmet Needs Exploration	Identify, understand, prioritize and share expectations, constraints and problems of internal and external stakeholders (e.g., customers, employees, etc.).	- Qualify unmet needs transformation into specifications to be shared with suppliers; - Inform this exploration by sharing information about supply opportunities; - Reconnect this exploration process with exploitation activities.
Supply Opportunities Exploration	Scout and assess ideas, resources, capabilities and or solutions of existing or potential suppliers, which can be useful to create and capture value.	- Bring knowledge about supply market structures and dynamics so to better evaluate the risk that lies behind any supply opportunity (e.g.,appropriability); - Reconnect this exploration process with exploitation activities.

Solutions Delivery	Exploit the value that lies behind existing or potential suppliers, with concrete returns for the company and its stakeholders	- Facilitate external coordination and co-evolution by leveraging its expertise in the governance of supplier relationship; - Facilitate external coordination and co-evolution thanks to its familiarity with suppliers (e.g., trust);

The value creation and capture process is often described as fuzzy and vague; however, some patterns have been identified, which often coexist in a company (Verganti, 2008). A 'Pull' type of model can be pursued. In such case, the process begins by exploring expectations, constraints and problems of internal and external stakeholders (e.g., customers, organizational departments, etc.). Here, the purchasing function can help in prioritizing unmet needs and translate them into challenges or requirements that can be easily shared with suppliers and maximize their creative thinking. *Supply opportunity exploration* activities follow: suppliers' potential for value creation and capture is evaluated according to the priorities identified during the first step. Here, the involvement of the purchasing function can be essential since this department holds information about supply market structures and dynamics and should be best at evaluating potential risks behind any supply opportunity. Furthermore, if the purchasing function is involved into both unmet needs exploration and supply opportunities exploration, information asymmetries, risk of opportunistic behaviors are reduced and exploration can be more effectively reconnected with the exploitation phase. Some studies found that supplier inclusion in NPD reduce costs (Handfield et al., 1999). However, there are many reports of suppliers incompetence and even project obstruction when unsuitable suppliers were selected (Zsidisin and Smith, 2005). Purchasing professionals take a total cost-of-ownership perspective that extends through the product's life cycle and reduce the probability of adverse selection which in turn help the organization to maintain efficiency (Schiele, 2010, p. 141). Finally, once suppliers' ideas, resources, capabilities and or solutions that match unmet needs are identified (and selected), exploitative activities take place. Here, the purchasing function should excel since it is particularly experienced in the selections of the right means to leverage suppliers' potential.

Also, a 'push' kind of model can be pursued. The firm starts with the exploration of resources, capabilities or solutions of (existing or potential) suppliers that are not already tapped. During this step the purchasing function is best at evaluating the risks and the level of appropriability that characterize each supply opportunity. Then, *Unmet needs exploration* follows: once that supply opportunities has been identified, the company need to understand if they can lead to concrete benefits. Thus, the purchasing function can be required to engage with external and internal stakeholders (e.g., customers, other departments) to understand whether there is good fit between the newly identified supply opportunities and their unmet needs. Once this evaluation has been performed, and agreement is achieved within the organization, exploitative activities can begin. Masco Corporation, for example, seeks to be ready to leverage on new technologies no matter where they can be found (Jaruzelski and Dehoff, 2010). A few years back, company representatives from the purchasing department noticed some interesting technology at a trade show – a wireless, battery-less switch, which they were sure would have applications in a house. "We vetted the technology, brainstormed specific applications for the home, and developed a pilot," recalls Thom Nealssohn, manager of innovation implementation services at Masco.

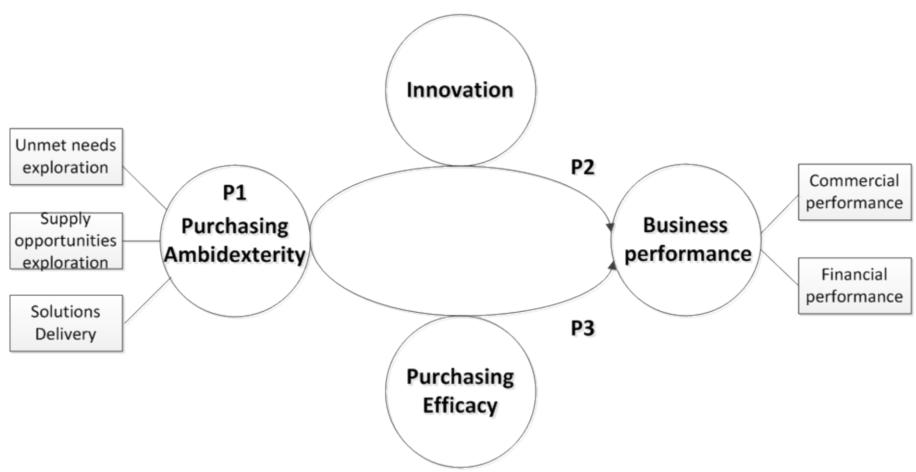
The simultaneous involvement of the purchasing function in the three processes discussed here above, regardless the pattern they may follow, denotes its ability "to cope with (and even welcome) conflicting ideas, paradoxes, ambiguity, and doubt" (Thompson, 2004), "to take more mindful decisions by not oversimplifying the decision alternatives" (Weick and Sutcliffe, 2006), "to embrace but also reduce uncertainty (O'Reilly and Tushman, 2008), or, in other terms, to be ambidextrous. Thus, we may conclude the following:

> *Proposition 1. Purchasing ambidexterity comprises three primary dimensions: unmet needs exploration, supply opportunities exploration and solutions delivery.*

4. Purchasing ambidexterity and business performance

Literature on how purchasing affects business performance is vast. Here we focus our attention on the impact of purchasing ambidexterity on performance and specifically on the outcomes of ambidexterity that mainly mediate this relationship. This analysis allowed us to identify two main outcomes: Innovation and Purchasing efficacy. Conceptually, the overall model is presented in Figure 3.

Figure 3. Conceptual framework



4.1. Innovation

Innovation refers to the amount of new things, or forms of a firm's renewal developed by the organization (Calantone et al., 2002; Nassimbeni, 2003; Roth, 1993; Sawhney et al., 2011) and for which the purchasing function may be the mediating agent. The ability to create and capture value is critical to firms' survival and success, especially in a world of slow growth, commoditization and global competition (Gassmann, 2006). Innovation, here, is considered to be "necessary". But what does innovation mean and how companies pursue it?

Sawhney et al. (2011) suggest that, although companies use to refer to innovation only from the perspective of new product development, managers should think holistically in terms of all possible dimensions through which their organizations can innovate. Specifically, the authors propose twelve dimensions of Innovation such as offering (e.g., develop innovative new products or services), platform (e.g., use common components or building blocks to create derivative offerings), solutions (e.g., create integrated and customized offerings that solve end-to-end customer problems), customer experience (e.g., redesign customer interactions across all touch points and all moments of contact), processes (e.g., redesign core operating processes to improve efficiency and effectiveness), organization (e.g., change form, function or activity of the firm), supply chain (e.g., think differently about sourcing and fulfillment), brand (e.g., leverage a brand into new domains) and others.

Purchasing ambidexterity can support the development of such innovation categories in different ways. First, purchasing involvement into *unmet needs gathering* helps other organizational constituents in understanding supplier potential and preserve disruptive innovations from getting rejected in their early development phase through internal skepticism and biased review process (e.g., Sheth et al., 2009). Also, by engaging with internal and external stakeholders (i.e., organizational departments, customers), the purchasing function can be inspired and can get a better sense of what the stakeholders needs and values.

Then, purchasing ability to conduct activities related to *supply opportunities exploration and exploitation* can be essential to the development of open-innovation models (Schiele, 2010; Wagner, 2012). In contrast to closed innovation approach, that is characterized by a protected, internal development kept secret and not shared with external players, Open innovation has been defined as ". . . *the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively*" (Chesbrough, 2010; Chesbrough, 2012). The value of this approach is widely recognized, especially in the rapidly changing technological domain (Asakawa et al., 2010). "Open innovation" allows to reduce the investment in innovation by leveraging external resources to save time and money in the innovation process: indeed, the development costs of innovation are reduced by the greater use of external technology in a firm's own R&D process. On the other hand it increases the possibility to obtain market revenues through the introduction of new sources of technology or product (and service) introduction, such as licensing out, spin offs, spill-overs and divesting businesses that are no more consistent with the company's strategy.

Thus, ambidextrous purchasing functions contribute to the development of a firm's dynamic capabilities. First, knowledge accessing and managing capabilities (Defee and Fugate, 2010; Lichtenthaler and Lichtenthaler, 2009) are benefited. For instance, purchasing involvement into *unmet needs exploration* enacts the lateral knowledge flow across functions and enables the vertical knowledge flow between the firm and its suppliers (Flynn et al., 2010; Piercy, 2009; Sheth et al., 2009), reconnecting exploration activities with exploitation activities (e.g., Push model). Similarly, purchasing involvement into *supply opportunities exploration* increases the effectiveness in the evaluation of suppliers' value (Handfield, 2010; Hult et al., 2004). Moreover, a firm's ability to co-evolve (Defee and Fugate, 2010; Lichtenthaler and Lichtenthaler, 2009) can also benefit from purchasing ambidexterity. Purchasing involvement into *Solutions delivery*, for instance, facilitates the management of webs of collaborations among multiple members of the supply chain for the purpose of generating noel capabilities and new value (innovations). To summarize, we propose the following:

> *Proposition 2. Purchasing ambidexterity positively impacts innovation, which in turn contributes to a firm's business performance.*

4.2. Purchasing efficacy

Purchasing efficacy refers to the ability of the purchasing function to transform its priorities (in terms of quality, flexibility, sustainability, innovation, etc.) into superior purchasing performance (González-Benito, 2007).

Since *unmet needs exploration*, *supply market exploration* and *solutions delivery* constitute complementary processes (for value creation and capture), doing more than one process increases the returns from doing the other process. Complementary actions in organizations, indeed, allow for the mutual enhancement of their respective contribution (Choi et al., 2008; Porter and Siggelkow, 2008). Following this line of reasoning, because of the simultaneously pursuit of exploration and exploitation activities, an ambidextrous purchasing function is expected to manifest higher efficacy in their daily practice.

For instance, by exploring supply opportunities with existing partners, purchasing function can get a better sense of existing suppliers' strategic capabilities for future potential opportunities and reinforce its selection, supplier engagement, supplier development, and risk management capabilities over time, which help to achieve and stabilize desired performance. Furthermore purchasing ambidexterity leads to increased collaboration across the partnering firms so, continuous interactions with internal and external customers allow the purchasing function to understand what really matter for the organization and update its priorities and strategies, rendering, enhancing its efficacy. A recent survey results suggest that in most cases, the primary consumer for information generated by market intelligence (both demand and supply sides) are category managers, who are seeking to enter into a new sourcing event for a specific category as part of an overall category strategy that aim at achieving functional priorities (Handfield, 2010, p. 46). Therefore, the following:

> *Proposition 3. Purchasing ambidexterity positively impacts purchasing efficacy, which in turn contributes to a firm's business performance.*

5. Conclusion, implications and future developments

In this study we have revised the PSM literature (Eggert et al., 2006; González-Benito, 2007; Handfield, 2010; Johnsen, 2009; Möller and Rajala, 2007; Möller and Törrönen, 2003; Piercy, 2009; Schiele, 2010; Wagner, 2012) through the lenses of ambidexterity (He and Wong, 2004; Lichtenthaler and Lichtenthaler, 2009; O'Reilly and Tushman, 2008; Raisch et al., 2009; Tushman and Reilly, 1996). This allowed us to shed new light on how the purchasing function can contribute to a firm's business performance (value created and captured).

From its ultimate survey (1.128 CPOs from organizations with annual revenue in excess of 1 billion US$), IBM found that top performing purchasing functions are those that succeed in combining three important traits: "they are capable (they had mastered core procurement competences), influential (they enjoyed outsized strategic influence) and innovative (they had successfully leveraged multiple sources and emerging technologies to bring innovation to the company they serve)" (Peterson et al., 2013). Consistently, in our paper top performing purchasing functions are suggested to be ambidextrous, or capable to simultaneously explore and exploit opportunities. Specifically, it insightfully emerged from the literature that *purchasing ambidexterity* is denoted by the purchasing involvement into three value creation and capture processes: *unmet needs exploration*, *supply opportunities exploration* and *solutions delivery*. The involvement of the purchasing function in these processes brings significant contributions (see Table 1) and has implications for innovation and purchasing efficacy, which in turn impact business performance (see Figure 1). From a theoretical point of view, thus, our study provides a conceptual model and a set of propositions that future research could operationalize and empirically validate.

Managerial implication of this paper are also significant. Purchasing functions aiming at supporting the creation and capture of value need to bring step changes in their capability to develop internal and external collaboration to access unmet needs and supply opportunities. They also need to take a longer term perspective as they look at opportunities beyond the next round of negotiation and the classic short term savings. Without doubts they have to extend the scope of their processes and practices and to continuously balance and prioritize their effort related to exploration and exploitation. From a managerial standpoint, the present study also raises a number of questions. The first one is organizational: Which kind of organizational structure is the most suitable? Should purchasing functions dedicate resources temporarily or permanently to exploration activities? In line with the structural differentiation logic of ambidexterity (Raisch et al., 2009), one could suggest for the segregation of the purchasing function into a number of sub-units with distinct capabilities and duties (e.g., operative procurement *vs.* life cycle sourcing *vs.* advance sourcing) (e.g., Schiele, 2010). Differently, organizations might prefer one integrated function who is held accountable for conducing exploration activities as part of their broader roles and responsibilities. Which alternative is best? Providing answers to this and the previously stated questions would provide a great contribution to PSM theory and practice.

The second one relates to measurement: How purchasing function measure the effectiveness and efficiency of their contribution to value creation and value capture? While the purchasing function has a strong record of saving measurement, value creation calls for a mindset change in terms of measurement. The third one relates to the management of the wider supplier base: To what extend purchasing functions can rely on their existing supply base for value creation and to what extend they need to scout for new suppliers or develop more subtle modes of collaboration. Depending of the rate of change in the firm environment, different answer could prove relevant. We consider these as relevant research directions that would enrich our understanding of the purchasing contribution to a firm's business performance.

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Foreign invested manufacturing company's components sourcing process in the context of China's processing trade

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Abstract
Processing trade activities in China significantly depend on *foreign invested manufacturing companies* (FIMC). Based on a case study of the component procurement process of a foreign electronics company engaged in processing trade in China, this study identifies three stages of the components sourcing process: (1) simple assembly stage, (2) component localization stage, and (3) supply chain integration stage. In addition, the case study suggests that the type of processing trade evolves from processing with supplied materials (PSMs) to processing with imported materials (PIMs) as the sourcing process proceeds through the three stages and the internal and external environments change.

Keywords: Global sourcing, processing trade, foreign invested manufacturing company (FIMC)

1. Introduction

Over the past three decades, China has experienced rapid economic growth, and has emerged as one of the most important markets and global sourcing destinations. (Christopher, Peck, & Towill, 2006; Tong & Zheng, 2008). Because of the availability of component suppliers, low costs and market accessibility, China has gained increasing importance among foreign manufacturing companies as one of the most attractive destinations for their manufacturing and investment. Since the mid-1990s the inflow of FDI (foreign direct investment) in China has increased significantly (Qu & Brocklehurst, 2003), largely driven by manufacturing sectors. According to the Chinese National Bureau of Statistics, the amount of FDI inflows in the manufacturing sector has increased remarkably and accounted for about 57.9% of total FDI inflows to China during the period from 1997-2011. Since the mid-1990s, FDI in manufacturing sectors has accounted for roughly 50% of Chinese exports and has played a very important role in China's export-oriented growth strategy. In addition, as shown in Figure 1, about 45-50% of China's total exports have been attributable to the processing trade, which has also been closely associated with manufacturing FDI inflows (Lemoine & Ünal-Kesenci, 2004; Xu & Lu, 2009). In fact, such processing activities in China significantly depend on *foreign invested manufacturing companies* (FIMC) (Ling, Shen, & Sun, 2009), which conduct about 80% of the total processing trade (Guillaume, Françoise, & Deniz, 2007). According to China's General Administration of Customs (GAC), processing trade is defined as *"the business activity of import of all or some raw and auxiliary materials, components, parts, mechanical components and packing materials and the re-export thereof as finished products after processing or assembling."* Basically, the flows of information, raw materials and finished products between supply chain partners play a vital role in implementing overall processing trade efficiently and effectively.

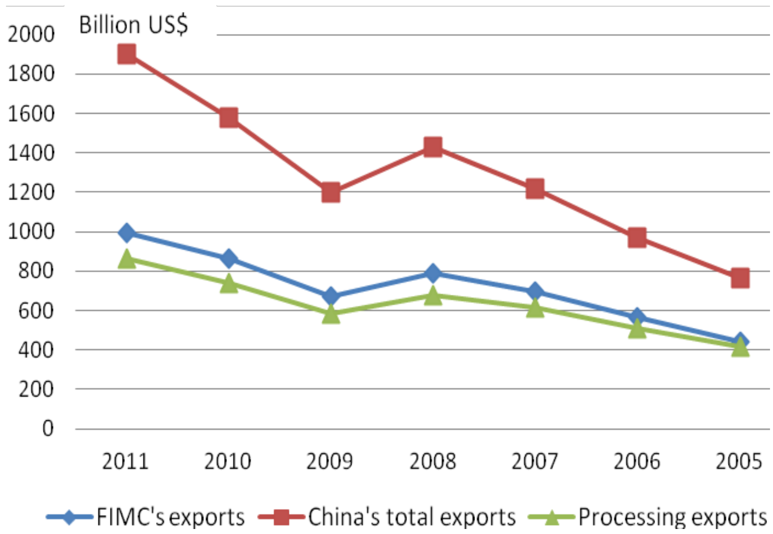

Figure 1. The structure of China's export trade

Despite the great contribution of FIMCs to the processing trade and the importance of supply management in processing activities, there has been almost no attempt in the supply chain management literature to investigate supply chain issues related to China's processing trade. To address this lack of research, this paper investigates the supply management of raw materials and components in the processing trade through a case study of how one FIMC organization built its integrated components sourcing system to efficiently and effectively operate in the processing trade in China.

2. Theoretical background

Sourcing refers to the integrated business process by which firms create value through the products and services procured from the external market (Smeltzer, Manship, & Rossetti, 2003). In the highly globalized business environment, global sourcing has increasingly been considered as a strategic tool for companies to gain a competitive advantage (Hatonen & Eriksson, 2009; Monczka & Trent, 1991; Trent & Monczka, 2003). However, in the course of

pursuing global sourcing practices companies are potentially exposed to a variety of risks, such as increased transaction costs, opportunistic behaviors of partners, currency exchange fluctuations, inadequate protection of intellectual property, socio-political instability and uncertain legal environment. Without proper failure-prevention initiatives and well designed processes, firms pursuing global sourcing may achieve unsatisfactory results due to the negative effects of such sourcing risks (Abdullah & Verner, 2012; Kang, Wu, Hong, & Park, 2012; Kotabe, Mol, & Murray, 2008; Narasimhan, Narayanan, & Srinivasan, 2010). Therefore, much previous research on the global sourcing has investigated either the benefits of global sourcing or how to manage the risks of global sourcing (Trent & Monczka, 2003).
Another research stream examines how individual firms gradually implement global sourcing in parallel with their process of globalization (Fagan, 1991; Hefler, 1981; Quintens, Pauwels, & Matthyssens, 2006). Adopting corporate internalization theory, many scholars propose global sourcing stage models to explain the process of globalization of sourcing. For example, Trent & Monczka (2003) view global sourcing as an evolving process from domestic purchasing to international purchasing to global sourcing. They further split the international purchasing and global sourcing stages into two sub-stages. The sub-stages for the global sourcing stage are: (1) integration and coordination of global sourcing strategies across worldwide locations, and (2) integration and coordination stage of global sourcing strategies with other functional groups. Global sourcing is closely linked with the geographical dispersion of a firm's activities. Therefore, the integration and coordination of such disperse activities has been emphasized as an important component of a global sourcing process (Trent & Monczka, 2003).

Much discussion of the global sourcing process in the literature puts emphasis on dealing with global sourcing strategy from the headquarters of multinational companies. However, the role of subsidiary companies located in foreign countries is becoming increasingly important as multinational companies offshore their manufacturing base. For example, U.S. multinational companies tend to move their manufacturing functions to developing countries and concentrate on new product development, marketing, and finance functions at corporate headquarters in the U.S. (Kotabe & Murray, 2004). As manufacturing bases are transferred to developing countries through FDI, subsidiary companies in the host countries are playing more active roles in component sourcing than their parent companies do. Despite this trend, studies on global sourcing have mainly focused on sourcing processes of multinational companies in the countries where their headquarters are located. A notable exception is Kotabe and Zhao (2002), which investigated the sourcing strategies and sourcing performance of subsidiary companies that operate their businesses in China and the U.S. Although there have been several studies on the sourcing strategy of subsidiary companies, few have attempted to examine how FIMCs in their host country apply component sourcing processes for effective and efficient sourcing operations. Therefore, the current study aims to fill this research gap and provide practical implications by studying the component sourcing and supply process from the perspective of an FIMC operating in China.

3. Methodology

The context of our case study is small- and medium-sized FIMCs in the electronics industry in China. The electronics industry faces low profitability, shortening product life cycles, and intense global competition. Many small- and medium-sized electronicw companies, including multinational companies, have moved their manufacturing functions to China in order to gain a cost advantage and expand their markets. It is very important for foreign electronics companies in China to establish a system which enables them to supply low-unit-cost and high-quality components. In doing so, the small- and medium-sized FIMCs are likely exposed to more risks in their sourcing practices than large FIMCs because of their inherent lack of resources and capabilites. They can potentially run into serious problems because they lack the resources and capabilities to effectively deal with legal, institutional, and socio-cultural differences and changes in the host contury (Kotabe & Murray, 2004). In addition, for large FIMCs dealing with the supply chain issues when they begin operations in a foreign location may be less difficult because they can entice their own suppliers to move to the foreign location with them. Due to the difficulties in internalizing all the functions in a supply chain, it is strategically important for small- and medium-sized FIMCs to process component sourcing efficiently and effectively. Because of these challenges they face, we have chosen to investigate the global sourcing process from the perspective of small- and medium-sized FIMCs in China.

3.1. Introduction to the case company

The case company supplies PSUs to the U.S. and all over the world. Their parent company is located in the U.S. and at the beginning of the case timeframe they ran their manufacturing facilities in South Korea and China. Later in the case timeframe they sold the facility located in Korea and currently operate two locations in China: (1) a factory in Hebei province, and (2) a location in Shanghai which handles R&D, purchasing, and sales functions. In this paper, we refer to the headquarters in the U.S. as “UP,” the manufacturing facility in Korea as “KP,” and the manufacturing facility in China as “CP.” In 1987, UP changed their organizational structure by focusing on R&D and marketing functions at headquarters and establishing KP in Korea to handle all their production. At the beginning stages KP served as a simple production base for UP, but gradually expanded its scope by adopting the R&D function. Their sales in Korea grew as the result of a good brand reputation and development capability. In 1996 KP established CP in China to help meet increased production requirements and cut production costs. At first, CP concentrated on stabilizing production and quality control, running a production assembly line for finished goods. As their quality control became stable and their experience in production in China grew, they become more competitive by reducing inefficiencies and optimizing their supply chain operations. Once the CP facility reached that stage UP sold KP to one of their suppliers because its strategic value had decreased. At that point, production operations were all deployed to the production line at CP and the R&D, global sourcing and sales activities for the Chinese local market were conducted by the Shanghai office.

4. Results and discussion

4.1. Analysis of the component sourcing process

Consistent with the stage models of supply chain integration discussed in the introductory sections, our analysis of the case data revealed that the case company passed through two intermediate stages on their path to supply chain integration. In the first stage CP focused only on assembly of supplied components. Later, they went through a process of component localization. After that they took steps to integrate their supply chain activities, both externally and internally. Each of these stages is described and discussed in more detail in the following sections.

Stage 1: Simple assembly with supplied components

Early in CP's operation in China, CP's main role was to assemble PSUs developed by UP and KP. CP's initial strategic goal was to cut manufacturing cost at the labor-intensive stage of final assembly by accessing China's low-cost labor resources. To achieve the goal and promote stable production at the beginning of operations in China, production of products characterized by relatively simple production and high demand volume was transferred from KP to CP. All the components needed for production were supplied to CP through KP's purchasing and completed knock down (CKD) method. Thus, CP first adopted the PSM (processing with supplied materials) type of processing trade, that is, most of the needed input components were freely supplied from KP to CP without paying tariffs and VAT (value added tax), and the finished products were exported from CP to KP or KP's customer (i.e., UP or UP's customers). CP received a processing fee from KP.
In this stage KP not only had to manage purchasing activity to support its own production, but also was responsible for purchasing and material control to support CP's production. Without the need for a purchasing function, CP simply processed and assembled raw materials and components supplied by KP and then exported finished products to final consumers of KP and UP. Thus, without having any supply management related activities such as supplier selection, negotiation, contract management, and purchasing control, CP relied solely on KP to manage its production and delivery control. This type of management enabled CP to produce high quality products and avoid potential risks from the use of unproven components sourced from Chinese local companies. Rather, CP could use the same proven components that KP had been using.

However, there were some problems in this initial stage. Delivery deadlines were often missed because of KP's purchasing lead time, preparation time for raw materials and input components, and delivery and customs time from KP to CP. Consequently, customers' delivery requirements were sometimes not met. Since CP's overall supply chain management depended heavily on KP, it was difficult to schedule their own production. Production typically began only after the required materials shipped from KP had arrived. Moreover, CP's production line was frequently stopped when incorrect materials were shipped from KP or material shortages occurred because of component defects. Even shortages of a simple component such as a resistor, which could be purchased in the local market and did not have a significant effect on product quality, could cause CP to stop a production line. These factors combined to lead to inefficient production. In order to resolve this shortage issue at CP, KP had to ship materials via express overnight airplane shipping almost weekly. The production line stoppage and express shipping of components to alleviate shortages led to additional costs and reduced the efficiency of operations. When component quality problems occurred during the production process, CP and KP often disagreed about the source of the problem, which caused solutions to the problems to be delayed.

In an attempt to solve these problems with shortages, component quality, and production problem identification KP delegated an engineer and a logistics manager to CP and got them invoved in CP's management, thus establishing an effective communication channel between KP and CP. Figure 2 shows the flows of components, finished products and payments among the three entities under the stage 1 PSM type of processing trade.

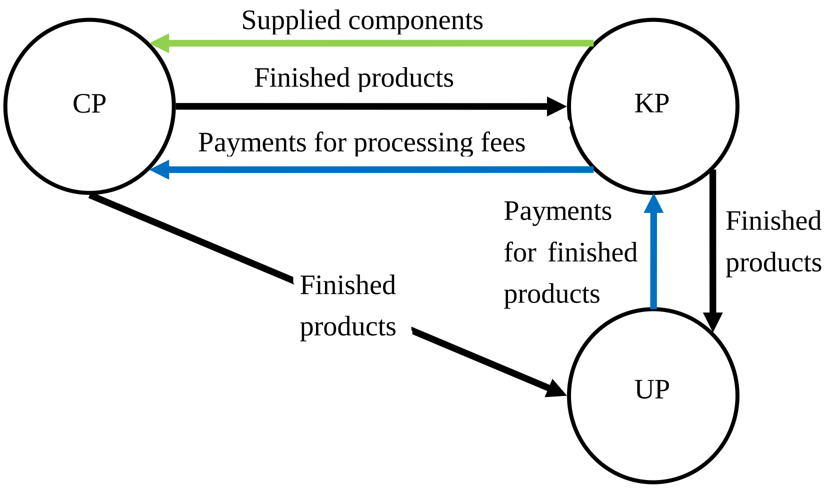

Figure 2. PSM type of processing trade between the three entities

Stage 2: Component localization

Although KP's involvement in CP's operations improved work coordination between CP and KP, it did not solve all the fundamental problems mentioned above. Those problems continued to make it difficult for CP to manage their manufacturing facility efficiently. Managers at UP, KP and CP came to recognize their need to address overall operational efficiency by improving their inefficient logistics process. They also recognized their need for cost reduction given the severe competition in the electronics industry. In particular, because the profit margins on PSUs which were mass produced at CP were very low, and material costs accounted for 60-80% of the sales price, reduction in components cost was an urgent need. Moreover, there was a cell phone battery charger developed by KP and produced by CP that was supplied to a customer who demanded low price with high quality which was producing consistent losses. To address the cost reduction issue and enhance operational efficiency, CP began component localization work in China.

In the early stage of component localization, the majority of localization efforts at the CP facility were focused on high volume and low-cost standardized components such as plastic cases, heat sinks, power cables, and transformers. Those components were localized first because their logistics costs were relatively high, handling them complicated KP's material warehouse management, and relying on KP to supply those components lowered CP's production flexibility. CP first developed plastic injection and transformer production lines in order to produce plastic cases and transformer components in-house rather than outsourcing, because those components are very critical to the overall quality of a PSU. CP also developed a production line for output cable components. Since the specifications of output cables required in the final assembly process of PSUs can vary depending on customer requirements, speedy and flexible supply of output cables played a crucial role in CP's operational efficiency and responsiveness to customers. Although high quality output cables were available in the marketplace at a low price, CP made the strategic decision to insource these components to gain the efficiency and responsiveness advantages. In the case of heat sinks, the localization was accomplished through collaboration with local suppliers because the heat sink components do not have a large effect on the quality of the finished PSUs, and outsourcing risk was judged to be low for that component.

Through this localization of high volume and bulky components, CP improved production efficiency and materials management, and cut their logistics and purchasing costs. However, CP faced difficulties when they attempted to localize core electronics components. CP's purchasing team was required to ship electronics components purchased in China to engineers in KP for component approval. However, KP engineers were extremely busy with their existing development work and did not have enough free time to test the electric requirements and quality of the components sourced from China. Because of this workload issue, the component change and approval process necessary for applying sourced components to production was often delayed. For example, an aluminum electrolysis condenser is an important component that affects the durability of PSUs. When CP submitted a locally-sourced aluminum electrolysis condenser to KP for approval KP engineers were reluctant to do so. Although the part met electric requirements during performance testing, it was difficult and costly for KP engineers to measure long-term quality and reliability. In general, because of their concerns about potential quality problems engineers in KP were reluctant to replace components that KP had developed and approved with components sourced from China. As a result they did not actively participate in the component approval process.

To solve this problem, CP established a component localization project team at its Shanghai location. The team consisted of a development engineer, component engineer, and purchasing manager. After sourcing all the electronic components, the cross-functional localization team inspected and tested the individual components, and also tested finished PSUs that were assembled using those sourced components. Engineers at KP and component engineers at UP were in charge of approving the tested components. It took a year or so to complete this component localization project and to apply the locally-sourced components to production at CP. As a result of this component localization process, they cut their component costs by 10%, achieved logistics cost reductions and improved production efficiency.

Stage 3: Supply chain integration

Through the process of component localization CP gained the ability to carry out their production with raw materials and components purchased in China. As local purchasing proceeded, the type of processing trade shifted from processing with supplied materials (PSM) to processing with imported materials (PIM). In addition to cost reduction in purchasing and logistics, local purchasing enabled CP to establish a flexible component supply system and thus deliver their products to final customers quicker than they could under the PSM system. Figure 3 shows the flows of components, finished products and payments among CP, KP, UP, and suppliers under the PIM type of processing trade.

Under the PIM system, however, supply chain management at CP became more complex than ever before and the need for efficient coordination and integration in overall supply chain activities (i.e., customer order handling, purchasing, inventory control, production scheduling and delivery management) among UP, KP, and CP became apparent. In fact, when the simple assembly process under the PSM system became stable, CP built an ERP system which could connect the CP facility with the UP and KP facilities. At that time it was used only to manage warehousing activity of raw materials and components in CP's facility. As local purchasing commenced, the same ERP system was also built in the Shanghai business unit. The purchasing manager at UP and the ERP engineer at KP regularly visited the factory at CP and the Shanghai business unit to train the employees in charge of the ERP system. In particular, the suppliers and components sourced in China were registered in the ERP system. By sharing in the ERP system information on the components sourced from Chinese and Korean suppliers, such as serial numbers, specifications, and prices, each entity was able to purchase raw materials and components no matter where production was done, whether it was at KP or CP or anywhere else. In addition, when KP and UP developed new products, engineers were encouraged to utilize components sourced in CP. They could research available components using the ERP system. In this way, flexible production and delivery systems which enabled development, component purchasing and production in any location were established.

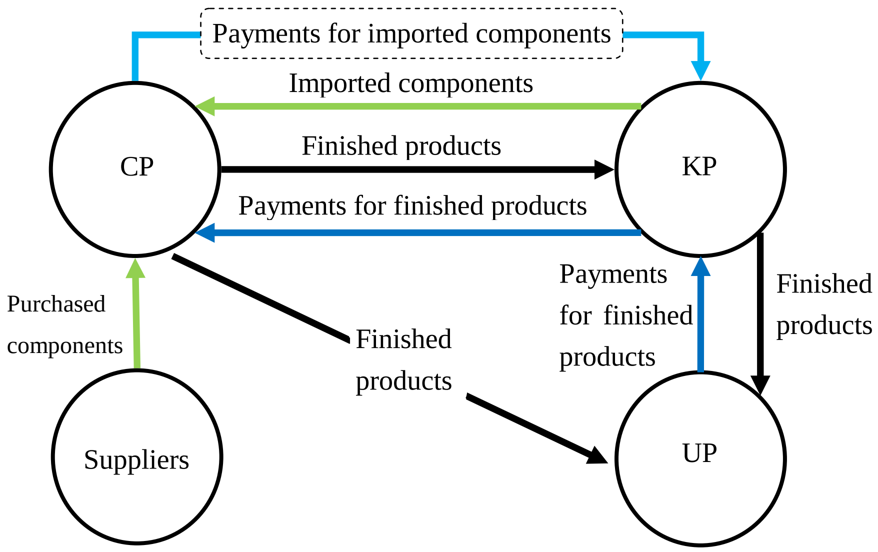

Figure 3. PIM type of processing trade between the three entities and suppliers

Because diverse functions such as sales, R&D, purchasing, production, and delivery were scattered geographically, the case company experienced the complexity of overall supply chain management. However, after component localization was successfully implemented, supply chain integration was enhanced by sharing information with suppliers and strengthening collaboration among the three locations through active utilization of the ERP system. As a result, CP improved not only cost efficiency and operational efficiency, but also operational capability and performance to levels far beyond those of the initial simple assembly process stage. As CP's competitiveness and strategic value increased, UP was able to sell KP to one of their suppliers. Even after KP was sold, collaboration between CP and KP was sustained through the previously established integration and collaboration system.

4.2. Component sourcing process and processing trade

The case company experienced a three-stage evolution of their component sourcing process in response to changes in and pressures from the internal and external environment, resulting in a state of supply chain integration. As part of this evolution the type of processing trade CP engaged in shifted from PSM to PIM. Table 1 below lists the basic characteristics and strengths and weakness of PSM and PIM that emerged from the interviews. It is clear that the major difference between the two types of processing is ownership of the materials supplied for assembly processing. Under PSM all the components supplied from KP to CP for processing still belonged to KP. CP received a processing fee from KP after assembling and processing, and finished products were shipped to final customers of either KP or UP.

Table 1. Comparisons between PSMs and PIMs

	PSM	*PIM*
Material ownership	Customer company overseas	Processing company in China
Source of cash flow	Processing charge	Product exports and sales
Strengths	• Cost reduction through processing and assembly • High quality is guaranteed • Low financial risk	• Cost reduction through overall operations process • Increases in overall operations efficiency and flexibility • Low dependence on KP and independent operation management
Weaknesses	• Heavy reliance on KP • Low efficiency and low flexibility • High logistics costs	• Quality risk • Financial risk • Additional investment

Under the PSM system CP was able to produce high quality products because they were able to use components from KP, and were able to focus on production and quality control. Using this processing method at the beginning of operations helped CP to minimize the risks caused by lack of business experience in China and to build up and maintain its processing operations in a stable manner. However, problems occurred because this method relied excessively on KP to support overall plant operations, including supplying materials. The problems included frequent lack of components, an inefficient production system, unnecessary logistics costs, and delays in delivery to customers. In addition, there were other conflicts such as disagreements between CP and KP in regard to who was responsible for quality problems, and, even worse, delays in troubleshooting the sources of the problems.

In contrast, material ownership belongs to processing companies under the PIM type of processing trade. In other words, CP imports raw materials and parts from KP or overseas suppliers by paying dollars without tariff taxes, and then maintains them as assets in separate duty-free warehouses within CP. Materials and components purchased in China are stored in general warehouses. The finished products that were assembled from parts imported from overseas and components purchased from suppliers in China were exported to the final customers (i.e., KP or UP). The shift to PIM enabled CP to cut costs significantly, as well as improve the overall efficiency and flexibility of operating plants. In addition, CP was elevated to independent agency where it could perform not only simple jobs such as assembly and fabrication, but also general supply chain management functions ranging from purchasing to delivery of the products. However, to support PIM processing the different locations had to invest in the establishment of an information tehnology system and in education, as the complexity of the supply chains and the need for information sharing among the different entities that comprise the case organization increased.

Likewise, although PSM and PIM are both implementations of the processing trade, they have significant differences in their characteristics and in their strengths and weaknesses. Based on which type of processing a trade company chooses, there are implications for the supply chain structure. Therefore it is very important to choose the right processing type according to the internal and external environment the company faces.

5. Conclusions

This study focused on analyzing the factors that influence component sourcing and choice of processing trade type through a case study of a company that entered into the Chinese market to manufacture power supply units (PSUs) at lower cost. The case analysis suggests a useful model of how to improve the supply chain outcomes of small-and medium-sized electronics companies engaged in processing trade in China. However, as our conclusions are based on the analysis of one case we hesitate to conclude that our suggested stage model is generally applicable to all companies engaged in the component sourcing processes. Therefore, in future research it would be meaningful to conduct comparative studies of component sourcing procedures of a variety of other manufacturing companies in China.

In addition, managers must understand the risks of doing business in China. Unlike other general trade activities, the processing trade in China requires different ways of managing imports/exports, finance, fulfilling orders, post-export activities, and so on. Without a clear understanding of the above tasks, companies are exposed to a variety of risks. One example is that materials imported through the tax-free processing trade must be stored in a separate duty-free warehouse, not in a general material warehouse located in a facility. Also, when those materials need to be outsourced, they must go through customs, resulting in possible delays. Likewise, special attention needs to be paid when it comes to managing materials based on the type of processing trade and the general trade because the way they are managed is quite different, and it can result in different supply chain structures according to the types of processing trade (PSMs vs. PIMs). In light of this, future studies may need to apply a supply chain perspective to the processing trade activities of manufacturing companies which have entered China.

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An exploratory study assessing value chain reconfiguration opportunities in oncology

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Abstract

The widespread adoption of e.g. continuous manufacturing in pharmaceutical industrial practice is not solely dependent upon the technical requirements of each process step. For such technologies to become more generally accepted the business case and impact on current industry value chain configuration(s) needs to be better understood. Current reconfiguration studies in this area have largely focused on a series of pharmaceutical candidates that are large volume (e.g. ACT and Metformin production in the order of 100-1000 tonnes/annum respectively).

Accelerated growth of the oncology market within the pharmaceutical sector has been widely reported in the literature e.g. Oncology drugs went from 10% sales of the top 100 best-selling drugs in 1998 to 18% by 2009. In addition, the IMS Institute for Healthcare (2012) forecasts $74-84 Billion of spending by 2017, making oncology the leading therapeutic area. It is argued that oncology may better exhibit characteristics of what may be the future of pharmaceutical industry (e.g. niche, personalised, high prices and costs, lower volumes, targeting for sub-populations) and, hence, inform opportunities and benefits for e.g. continuous operations on the wider pharmaceutical industry.

An analytical framework/model, previously developed, is utilised to enable a systematic assessment of a series of candidates that are representative of the wider oncology market e.g. including low volume, niche, patented drugs with high QALYs (quality-adjusted life years) through to higher volume generics with a history of shortages.

This working paper proposes a series of candidates and emerging product-process archetypes in oncology – classified as 'New Niche', 'Old Niche' and 'Established Generics' - for further investigation, in order to explore different future scenarios and models for value chain reconfiguration.

Keywords: oncology, pharmaceuticals**,** value chain, continuous manufacturing,

Introduction

Despite today's service levels within the pharmaceutical sector reaching 99% OTIF levels and gross margins averaging ~75% (see figure 1), there is a continuing shift away from the traditional large volume 'blockbuster' drug production model. The current supply base is recognised as being inflexible having been built to serve the large volume blockbuster model of the past. However, only recently, it has become clear that this model is obsolete (Srai, Badman *et al*, 2014). As a result there are potential market failures ahead in terms of:

- Current inflexible manufacturing capacity: no longer fit for purpose in supporting new products and treatments which require multiple supply solutions, that can sustain a broad range of product volumes and patient populations
- The emergence of new technologies and therapies are changing the manufacturing

and supply chain landscape which require alternative production processing and business models (e.g. more continuous processes, novel enzymes, post-dosed actives, diagnostics), involving smaller production plants with more distributed local-to--market manufacturing options

- Distressed national health budgets and increasingly stretching patient health targets require more affordable treatments, that can no longer carry the costs of excessive inventory and batch processing quality failures that are estimated to cost the global industry £20bn/y.
- Drug and treatment complexity that require products that better facilitate patient compliance for improved patient outcomes. This situation can present an opportunity for those SCs that can re-invent themselves for this new context.

Company	Gross margins (%)
Pfizer	81.3
Novartis	67.1
Roche	73.4
GSK	69.5
AZ	79.8
Eli Lilly	76.4
Average	**74.6**

Figure 1. Gross margins for 6 of the top 10 leading pharmaceutical companies (source: figures retrieved from the Financial Times, October 2014)

In parallel, advances in stratified and personalised medicines will require levels of product customisation that make the batch centric production models of today incapable of economically supplying product varieties (SKUs) at the smaller volumes required, and at the speed increasingly demanded by end-users (patients and payers) without the costly 'buffer' of huge inventory.

It is argued that the oncology segment may best exhibit the characteristics of what may be the future of pharmaceutical industry (e.g. niche, personalised, high prices and costs, lower volumes, targeting for sub-populations and therapy areas) and, hence, inform opportunities and benefits for e.g. continuous operations on the wider pharmaceutical industry.

Oncology context

Cancer remains the leading cause of worldwide deaths, estimated to be in the order of 13% (WHO, 2014; American Cancer Society, 2011) and incidence rates are predicted to also increase worldwide e.g. from 14 million annual cases in 2012 to 22 million within the two decades (WHO, 2014). In terms of demographics, incidence and mortality rates for most cancers are increasing more quickly in (a) developing countries with the adoption of western lifestyles (Jemal *et al*, 2010) and (b) ageing populations. Hence, cost of care is becoming a critical issue because of the lower purchasing power of these two segments.

Currently, cancer care consists of a combination of the three available treatment types (i.e. Surgery, Radiotherapy, Chemotherapy) with success dependent on type of cancer treated, stage discovered, and treatments available (American Cancer Society 2011). This research specifically focuses on the chemotherapy drug treatment area of care and the opportunities for technology-enabled VC reconfiguration, which may reduce such costs, and satisfy 'unmet needs' within these segments.

The IMS Institute for Healthcare (2012) has reported growth of 6-15% between 2008 and 2013, as opposed to 1-7% for the wider pharmaceutical industry. In addition, KPMG (2011) forecasts that oncology market will continue to grow faster than other leading therapy areas: 5-8% annually between 2010-2015 compared to e.g. 1-4% for Cardio-Vascular drugs) - see Figure 2. Furthermore, Bagwell et al. (2011) has reported the accelerated growth of the oncology market within the pharmaceutical sector e.g. Oncology drugs went from 10% sales of the top 100 best-selling drugs in 1998 to 18% in 2009. In terms of spending, IMS Institute for Healthcare (2012) forecasts $74-84 Billion in 2017 in the developed nations, making it the leading therapeutic area with the major drivers being increased incidence of cancer and therapeutic development (Jemal *et al*, 2010)

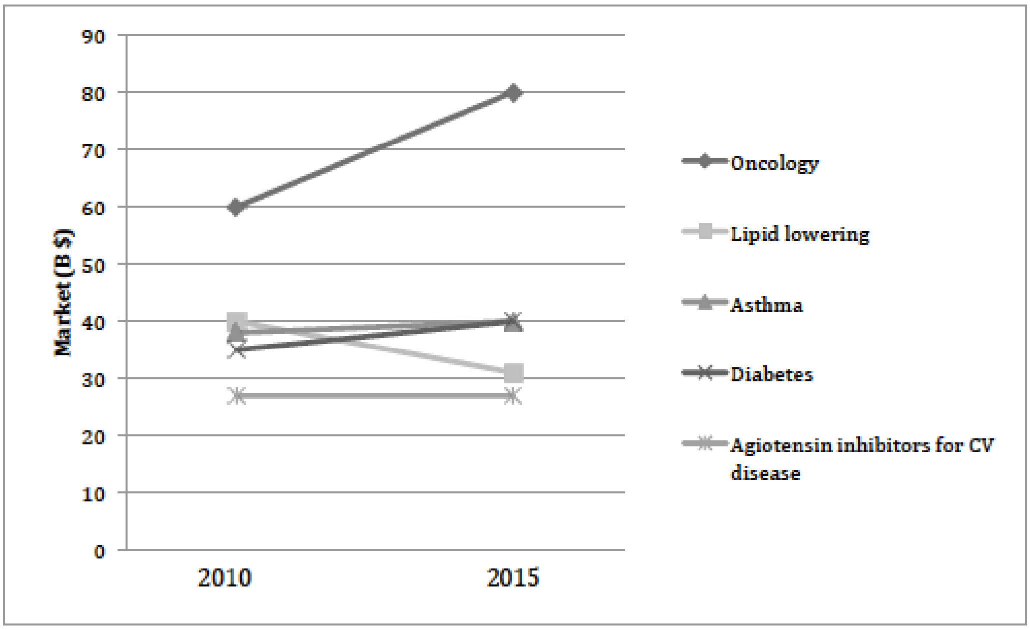

Figure 2. Growth forecast for the major therapeutic areas between 2010-2015, adapted from KPMG (2011)

Methodology and case examples

A number of cases exploring intervention examples to develop new or radically different product-process reconfiguration models that can support major breakthroughs in total value network performance are currently under examination. These include exploring continuous-processing and crystallisation in previously batch-process-oriented Pharma, implications of additive manufacturing in component manufacture that replace traditional subtractive processes, and post-dosing product finishing models that enable more near-market supply (Harrington *et al*, 2013; Harrington *et al*, 2014; Srai, Badman *et al*, 2014; Srai *et al*, 2014; Srai, Christodoulou and Harrington, 2014; CMAC 2014)

Although only a small majority of the models examined have reached industrial viability, as each requires significant technology breakthroughs in formulation, production processing and/or delivery models, redesign alternatives and options may be considered that might be suitably informed by a broader value network analysis and systems optimisation agenda. These conceptual network redesign studies look to emphasise different product, process and business models that enable new or previously elusive markets to be served economically. In building the business case**,** the first stage involves exploration of current state process models with step 2 aims to map/generate future process and network design options and scenarios involving e.g. candidate products. Current reconfiguration studies in this area have largely focused on a series of pharmaceutical candidates that are large volume (CMAC, 2014) e.g. ACT and Metformin production in the order of 100-1000 tonnes/annum respectively. In this preliminary scoping study, the approach is adapted to explore value chain opportunities in the low volume oncology segment.

Oncology Drug Candidate Selection

This section summarises the methodology used to select the case study candidate drugs, and the underlying rationale to support it.

The overall purpose of the analytical framework is to test, propose and forecast potential reconfiguration opportunities of existing value chains. Thus, it is of paramount importance to select the case studies with the highest potential outcomes, meaning:

- Candidate(s) with an interesting business context for reconfiguration
- Candidates with a sufficient amount of data to be able to conduct the case studies (secondary data)
- Case studies with higher probability to experience reconfiguration, and thus in this case, higher chance to benefit from a technology disruption e.g. CM

Step 1: Assesses different oncology drugs at a molecule level, deleting duplicates from drugs produced by different firms, as well as combined drugs.

Step 2: Drug segmentation constitutes the next selection criterion. Two segments exist: e.g. small molecules and biologic drugs. For small molecules, production processes are often well understood and straightforward, while biologics are often produced through very complex, difficult to certify processes (Garrison 2010). Thus, on the one hand, small molecules are more amenable to technology disruption e.g. CM (because of ease and level of understanding of their production processes), on the other hand, they are more subject to generic competition (because of the low barrier to entry after patent expiration compared to the high manufacturing barrier to entry in biologics).

Step 3: First data availability screening which examines process chemistry, data availability and molecule chemistry. The objective here is to be able to understand the production or chemical process for synthesising the drug, with special focus on API as it commonly encompasses most of the value. Access to data is critical at a later stage of screening, as it is beneficial in order to evaluate the opportunities for amenability to a technology disruption e.g. CM

Step 4: the drugs' business context is examined. By capturing e.g. target population, therapy area, price, patent state, etc., the purpose is to detect interesting business states that may benefit from a possible reconfiguration (e.g. inaccessible drug because of price or cost, drug with frequent shortages etc.) Finally, amenability to technology disruption e.g. CM and availability of supply chain data serves to highlight the drug candidates with highest potential for reconfiguration, and with enough data to compare reconfiguration opportunities and future states and scenarios with current states.

Using this candidate drug selection rationale (see figure 3), a shortlist of 7 drugs was selected as potential candidates for future research. Starting from 369 cancer drugs currently in the pipeline (i.e. in clinical test or commercialisation), and looking at the molecule level, a deletion of duplicates from competing brands or combinatory drugs resulted in 144 molecules of interest. Small molecules constitute 110 of these, from which 47 drugs have available manufacturing or chemical production processes. From these shortlisted drugs, focus on business case led to the selection of 7 candidate drugs for this research.

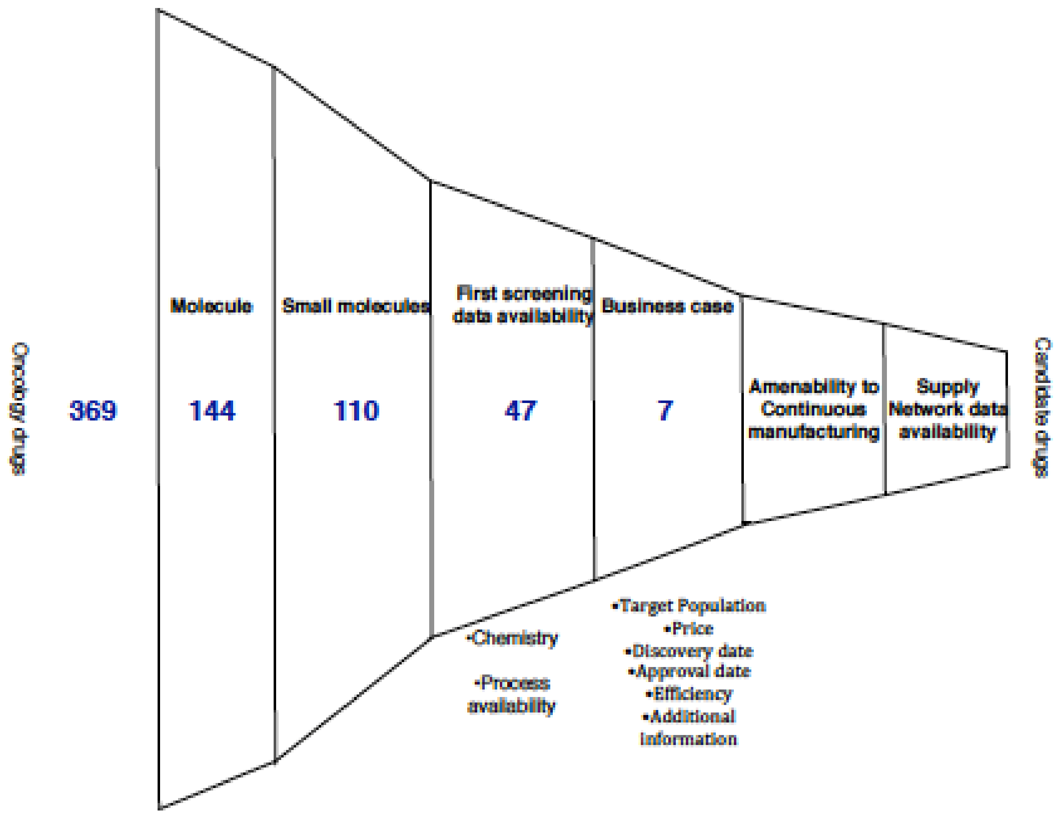

Figure 3. Oncology drug candidate selection rationale

An analytical framework/model, previously developed (Srai *et al*, 2014), is utilised to enable a systematic assessment of a series of these candidates that are representative of the wider oncology market e.g. including low volume, niche, patented drugs with high QALYs (quality-adjusted life years) through to higher volume generics with a history of shortages. Table 1 summarises a set of emerging product-process archetypes in oncology, identified in this scoping exercise – classified as 'New Niche', 'Old Niche' and 'Established Generics' – and the associated oncology candidates identified for future study (presented in figure 4).

Table 1. Emerging product-process archetypes in oncology and associated candidates

Product-Process Archetype	Products	Volume	Cost	Patent	Inventory	Production Attributes	Clinical Trials	Service Levels	Shortages
New Niche	XAP AXP SUP	Low	High	Yes	High	High Quality; In-house	High potential	High	None
Old Niche	EPG CYG	Medium	Medium	Recently expired	Medium	Downgraded plants	Lower potential	Medium	Occasional
Established Generic	PAG MEG	High	Low	No	Low	Outsourced	Support drugs	Low	Frequent

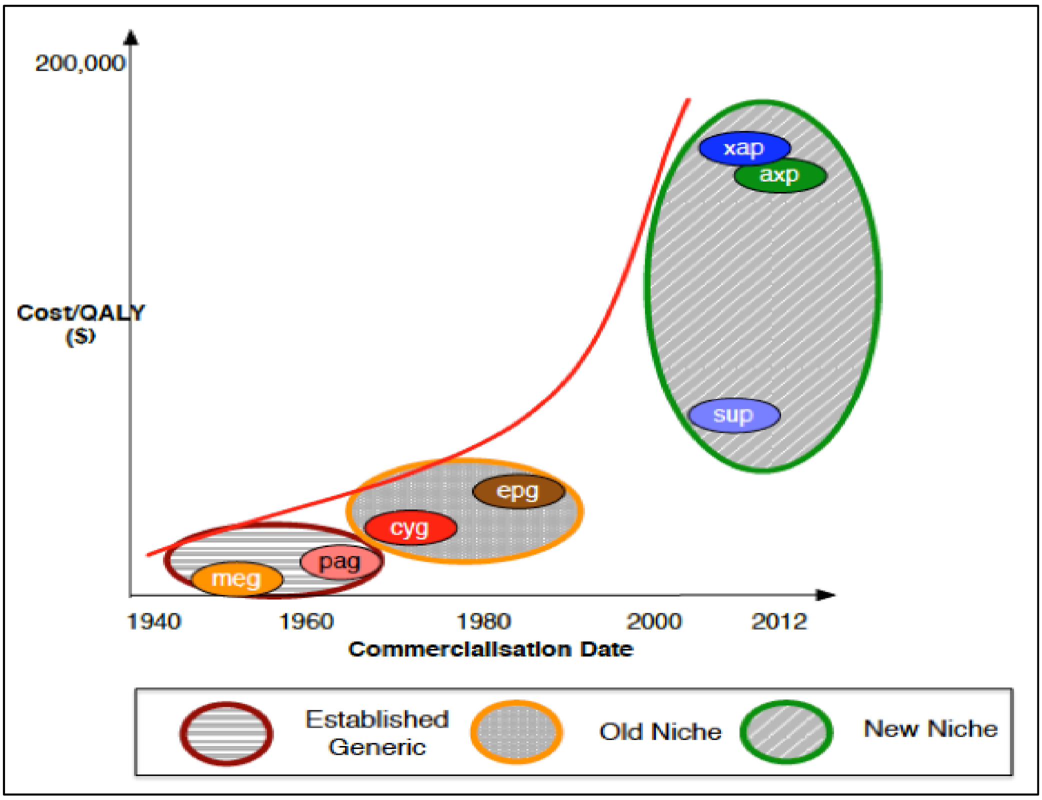

Figure 4. Seven candidate oncology drugs in terms of Cost/QALY v. Commercialisation date

The ‘*New Niche*’ segment exhibits high potential benefit in lowering inventory (from primary to E2E). Other potential benefits are proposed e.g. lowering lead-time to market (primary, secondary and end-to-end), easier scale up (primary and secondary), cost (secondary, packaging) and mobility/adaptability (secondary, packaging). This segment has high potential for more clinical trials and in unlocking new therapy areas, and to be able to scale up accordingly, in a potentially easier manner. Inefficient supply chains, driven by the drug patent state may be improved e.g. lowering very high inventories, cost, and preparing for future generic competition. Candidates identified for this segment are as follows:

- ‘XAP’ – high cost personalised product under patent with a very low target population,
- ‘AXP’- product under patent with high cost/low target population
- ‘SUP’ – product under patent, high cost/low target population, facing generic competition in the short to mid-term future.

The ‘*Old Niche*’ segment presents highest potential benefit in enhanced process control, reliability and safety (across all the sub-systems), and improved quality, purity and consistency (secondary, packaging and E2E), which may help lower shortages’ frequency. Cost reduction potential (especially in primary) may help this segment regain the recently lost economic incentive (from patent loss). There is potential in unlocking therapy areas is of medium importance, supported by medium potential benefit for easier scale-up. Candidates identified for this segment are as follows:

- ‘EPG’ – product recently off patent, applied to a large target population (breast cancer)
- ‘CYG’- a product off patent, facing high competition.

The ‘*Established Generic*’ segment exhibits highest potential benefit in enhanced process control, reliability, safety; and improved quality, purity, consistency (across all the sub-systems). This may help lower the frequent recalls and shortages that are occurring in this segment. Another important potential benefit is cost reduction (from primary to E2E), which may increase the economic incentive for this segment. Candidates identified for this segment are as follows:

- ‘PAG’ – high volume generic drug, with a long cycle time and
- ‘MEG’ – high volume generic drug applied to many cancers.

Future work

Ongoing research is looking at mapping current state profiles for the seven oncology candidates and capturing critical sub-systems that may be affected by a shift to e.g. continuous manufacturing using a range of 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 (initial focus on continuous processing and crystallisation in pharmaceuticals).

These scenarios may need 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 will depend on various disruptive influences that challenge the current value network model and introduce possible product or product-service models.

Conclusions

An analytical framework, previously developed and tested for large volume Pharma candidates, was deployed as part of a scoping exercise in order to explore potential interactions between value network sub-systems in the oncology market (e.g. Clinical, Primary/Secondary Manufacturing, Packaging and Distribution, E2E Supply). The approach informed the selection of a series of preliminary candidates in oncology to be investigated further as part of a wider research agenda.

Acknowledgements

We would like to acknowledge the support and funding from the EPSRC Centre for Innovative Manufacturing in Continuous Manufacturing and Crystallisation (CMAC) for supporting this research activity.

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