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20th Cambridge International Manufacturing Symposium | 29-30 September 2016

Architecting the digital supply chain

the implications of digitalisation for global manufacturing

PROGRAMME
& ABSTRACTS

IfM MANAGEMENT TECHNOLOGY POLICY

UNIVERSITY OF CAMBRIDGE

AGENDA | THURSDAY 29 SEPTEMBER

09.00	Registration and refreshments
09.30	**Welcome and introduction:** Dr Jagjit Singh Srai, Head, Centre for International Manufacturing, **IfM, University of Cambridge**
09.45	**Digital factories: new opportunities for managing uncertainty and variation** Denis Malone, Global Advanced Manufacturing Manager, **ABB**
10.30	Refreshments
11.00	**Digital-technology enabled S&OP process for integrated manufacturing and supply networks** Haydn J Powell, Global Supply Chain Manager, **Caterpillar inc**
11.45	**They picked it before you've clicked it** Catherine McDermott, Operations Director, **Celesio UK**, formerly UK Supply Chain Director, **Amazon UK**
12.30	Lunch and networking
13.45	**IKEA Industry: supply chain of the future** Per Berggren, Industrial Strategy Manager, **IKEA Industry**
14.30	**Wavin Group perspective on digitization** Richard van Delden, Executive Director Supply Chain, **Wavin**
15.15	Refreshments
15.45	**Integrated supply chain in the cloud** Mark Darbyshire, Vice President, **HANA Cloud Platform, SAP**
16.30	**Setting the future research agenda**
17.15	Wrap up and close of session
19.00	Symposium Dinner at St John's College

AGENDA | FRIDAY 30 SEPTEMBER

08.30	Registration and refreshments
09.00	**Digitalizing the manufacturing enterprise of the future: insights from 20 years of technology research** Ken Boyer, Professor of Operations Management, Fisher College of Business, Chair, Department of Management Sciences, Ohio State University
	Tool or toy? Generating economic value from additive manufacturing Matthias Holweg, Professor of Operations Management, Said Business School, University of Oxford
	Intelligent industrial automation in factories and elsewhere Professor Duncan McFarlane, Head, Distributed Information and Automation Laboratory, University of Cambridge
11.00	Refreshments
11.30	**RESEARCH THEMES** | SESSION ONE Digital supply chains - special session Sustainability - special session Global manufacturing and China - special session
13.00	Lunch
14.00	**RESEARCH THEMES** | SESSION TWO Network design I Digital transformation I Digital value networks I Sustainability I Global manufacturing and China I
15.30	Refreshments
15.45	**RESEARCH THEMES** | SESSION THREE Network design II Digital transformation II Digital value networks II Sustainability II Global manufacturing and China II
17.00	Close

Digital supply chains (Chair: Bart MacCarthy)

Special session

Digitisation (or digitalisation), combined with changes such as the cloud, the internet of things and the availability of big data, will affect many aspects of future supply chain design, configuration and location. Supply chain relationship management, supply chain coordination and control, and order fulfilment processes will be equally affected. The panel session will explore these themes and present perspectives on how these changes will affect future supply chains.

Speakers:

Bart MacCarthy, Professor of Operations Management, Nottingham University Business School, Digitalisation and supply chain monitoring, Data rich supply chains present increased opportunities for prime supply chain entities to monitor both individual supplier performance and the performance of a supply network. The contribution will discuss how time compression in data transmission matched with appropriate methods, models and techniques will enhance the ability of the prime to detect poor performance, whether delivery or quality, identify routes for improvement and recovery and opportunities for development.

Jagjit Singh Srai, Head of Centre for International Manufacturing, IfM, Cambridge University, Contextualising digital supply chains – perspectives from academia and industry, Conceptualizing the digital supply chain, Experimentation in digital supply chains – some examples regarding patient centric Pharmaceuticals, Emerging digital scenarios – observations from industry

Steve New, Assoc. Prof of Operations Management, Said Business School, Oxford University, Digital Governance, Supply chains and provenance; supply chain transparency; right-to-know; privacy; supply chain security; big data; cloud computing. How much should organizations know about their extended supply base, and how much should they tell?

Constantin Blome, Professor of Operations Management, University of Sussex, Sustainability and digitisation

Antony Paulraj, Professor of Operations Management, University of Manchester, Supply chain contracts and finance

Nishikant Mishra, Assoc. Prof of Operations Management, University of East Anglia, Digital Product Design and Order Fulfilment

Sustainaibility (Chair: Arild Aspelund)

Special session

Speakers:

Professor Peter Ball, The University of York. Peter is professor in operations management and is an expert in how operations can be designed and improved. Application areas span manufacturing, supply chain and services.

Dr Mukesh Kumar, University of Cambridge. Mukesh is university lecturer in operations management and does his research on risk, resilience and sustainability in the area of manufacturing and supply network research.

Associate Professor Malena Ingemansson Havenvid, Norwegian University of Science and Technology. Malena does research on technology development and innovation in manufacturing firms. Her main interests are how interaction in business networks affects the achievement of sustainable innovation.

Professor Arild Aspelund, NTNU. Arild is professor in International Marketing and is engaged in research on green innovation and sustainability among international manufacturers.

Through short presentations of experienced sustainability researchers and an open round table debate, we seek to set the future course for research in sustainable manufacturing and sustainable supply chains.

Global Manufacturing and China (Chair: Yongjiang Shi)

Special session

Speakers:

Mr. Jack Lyu - Incentive mechanisms to drive perpetual motion in enterprise development

Mr. Jack (Ke) Lyu is a Vice President of Human Resource Management Department, Executive Secretary of Human Resources Committee of Huawei Technologies Co., Ltd.

Mr. Tian Tao - The third road: an institutional experiment from a Chinese company

Mr. TIAN Tao is an advisor of the Huawei International Advisory Council, Co-Director of the Huawei Management Research Institute at Zhejiang University, and a tutor at the New Hua Du Business School

RESEARCH THEMES | SESSION TWO: 11.30

Network Design I (Chair: Harri Lorentz)
Situation awareness as a building block of purchasing and supply management capability
Harri Lorentz
Skills design of home delivery operations by tricycle: For improving service quality in last mile stage
Koichi Murata, Hiroshi Katayama
Linking government policy and supply network capabilities for design and transformation of supply chains - an investigation into interventions, configuration and influences
Arsalan Ghani, Jagjit Singh Srai

Digital Transformation I (Chair: Laird Burns)
Mastering the digital transformation requires excellence in fundamentals: Partial effectiveness in supply chain design can be expensive
Laird Burns & Fan Tseng
How is Big Data Transforming Operations Models in the Automotive Industry: A Preliminary Investigation
Gary Graham, Patrick Hennelly, Bethany Tew, Royston Meriton
A decision support model for the market development process for emerging markets in the automotive industry
Thillai Sivakumaran, Lia Heyne, Michael Toth

Digital Value Networks I (Chair: Ettore Settanni)
Assessing the economic connectedness of the UK pharmaceutical and digital sectors by Input-Output Analysis
Ettore Settanni, Jagjit Singh Srai
The role of digital technologies in the innovation of collaborative networks: the case of the ornamental stones in Portugal
Agostinho M. Antunes da Silva. J. M. Vilas-Boas da Silva, Isabel Duarte de Almeida
Digital Global Value Chains and the alternative upgrading path: innovation with end-user
Evodio Kaltenecker and Afonso Fleury

Sustainability I (Chair: Arild Aspelund)
Sustainable manufacturing: steps for leading organisational change
Peter Ball
CEO's Motivation and Leadership Style: Effects on Sustainability Practices in Manufacturing Firms
Ann Elida Eide, Erik Andreas Saether, and Arild Aspelund
Can Life Cycle Product Communication Contribute to Greener Business Models?
Marit Moe Bjørnbet

Global Manufacturing and China I (Chair: Yongjiang Shi)
How Huawei Transformed R&D Management: A Process-based Model
Lanhua, Li & Bin Guo
Someone Rises Someone Falls: Exercise of Dynamic Capability vs ad hoc Problem Solving when Facing Similar Challenge from Intellectual Properties
Haoyu Zhang, Xiaobo Wu, Hongqi Xu
Financial management transformation in Huawei
Xiao Chen & Can Huang
Collaboration behaviors in the development of telecommunication standards: a perspective of patent network analysis
Haoyu Zhang, Huijun Shen

Network Design II (Chair: Naoum Tsolakis)
Modelling 'Green' Paracetamol Supply Chain Operations Defined by Renewable Chemical Feedstocks in England: A System Dynamics Analysis Naoum Tsolakis, Jagjit Singh Srai
Exploring Interdependence and Industrial Dynamics in the Business Ecosystem of the Chinese Rare Earth Industry Yinjie Zhou & Yongjiang Shi
International Operations Management (IOM) of Multinational Corporations (MNCs): to pursue a holographic understanding for their IOM network systems Xingkun Liang, Yongjiang Shi

Digital Transformation II (Chair: Mukesh Kumar)
Big Data and Supply Chain Management: A Marriage of Convenience? Royston Meriton and Gary Graham
Digitalisation of Supply Chains: A dynamic capabilities perspective Denis Niedenzu, Mukesh Kumar, Rengarajan Srinivasan
Towards the development of cyber-resilient supply chains Sunil Sarferaz, Mukesh Kumar
Transfer Activities of Lean Management to Other Industries -Transplanting Heijunka Concept for Leanised Operations Hiroshi Katayama

Digital Value Networks II (Chair: Mark Phillips)
Convergence in health and medical technologies: the development of new value networks Mark A Phillips, Jagjit Singh Srai
Developing a model to conceptualise a more digitally connected pharma/healthcare value network Tom Burge, Tomas Harrington
Customer Value Assessment in Pharmaceutical Industry Leda T Todorova-Aleksieva

Sustainability II (Chair: Arild Aspelund)
Understanding the role of Sustainability in Mergers & Acquisitions from the perspective of Supply Chain Management – How green is the deal? Pavan Manocha, Jagjit Singh Srai and Mukesh Kumar
The Emerging Market Manufacturing Business Groups (EMBGs) and the Interplay between Innovation in Environmental Sustainability, Digitalization, Internationalization and Corporate Governance Structures: The Case of Turkish Holding Companies Anil Yasin Ar, Aysun Ficici
Bridging the gap between theory and implementation for new business models for sustainability Annik Magerholm, Haley Knudson, Sunniva Bratt Slette

Global Manufacturing and China II (Chair: Yongjiang Shi)
Partner Selection, Legitimacy and the Growth: A Case Study of the Social Enterprise Ning Cai, Yuting Zhang , Yong Li, Jing Chen
Internationalization through business model innovation: A perspective of legitimacy Ziyi Zhao
To License or Sell: A Study on the Patent Transaction Modes in China Huijun Shen, Can Huang
How do Chinese Firms Benefit from R&D Internationalization in Europe Developed Economies? Exploring the moderating roles of Absorptive Capacity and Entry Jiang Wei Yang Yang Qiyu Zhao

Denis Malone **Global Advanced Manufacturing Manager** **Medium Voltage Products** **September 2016**

Digital Factories

New Opportunities for Managing Uncertainty & Variation

Power and productivity for a better world™ ABB

The Digital Factory
Optimism!

"Of the many diverse and fascinating challenges we face today, the most intense and important is how to understand and shape the new technology revolution, which entails nothing less than a transformation of humankind."

"… think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few."

-Klaus Schwab, World Economic Forum 2016

"It has become almost commonplace that the world is experiencing a scientific and technological revolution."

"It is beyond our knowledge to know whether the computer, nuclear power, and molecular biology are quantitatively or qualitatively more "revolutionary" than the telephone, electric power, and bacteriology."

-National Commission on Technology, Automation and Economic Progress 1966

"You can see the computer age everywhere but in the productivity statistics."

-Prof. Robert M. Solow, Massachusetts Institute of Technology, 1987

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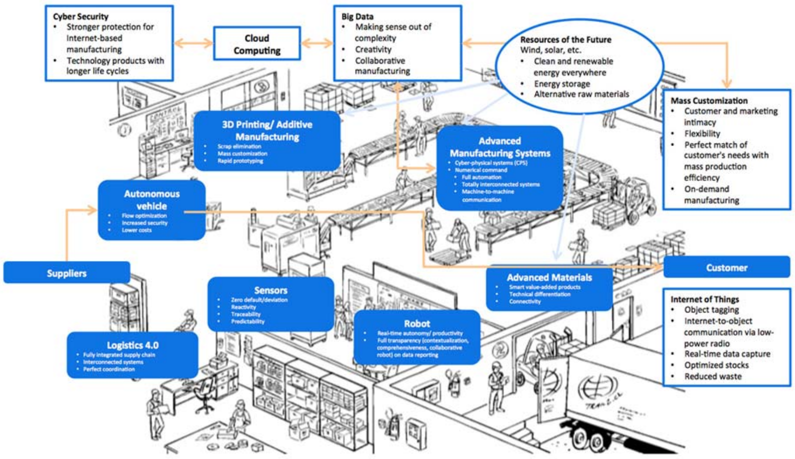
Industry 4.0



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The Digital Factory: Key areas for Advanced Manufacturing

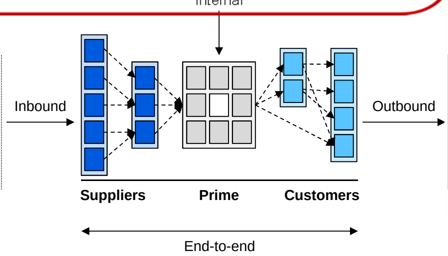
2 Digital Factory Design Digital 3D modelling systems for factory layout design, process and material flow simulation

3 Real-time Factory Scheduling Advanced factory execution systems with sensor-enabled, smart devices, real-time data KPI monitoring, predictive maintenance

4 Flexible Factory Automation Advanced manufacturing plant/machine reconfiguration, scale flexibility, varied levels of human-robot-collaboration

5 Digital Production Processes Application of digital production processes (e.g. additive manufacturing, continuous processing) with advanced process analytics

1 Automated e-Sourcing Seamlessly connected automated replenishment in line with real-time KPI monitoring, with predictive disruption analytics (all tiers back to mine)



6 e-Commerce Fulfilment Web-based order management (configuration, pricing etc.) and inventory deployment to multiple points of sale, covering last-mile and direct delivery (all tiers through to end users)

10 Product Lifecycle Management Nextgen PLM systems that provide accurate, up-to-date product information accessible throughout the value chain and product lifecycle

9 Digital Supply Network Design Design tools to architect supply network configuration – optimisation and visualisation of site location, capacity, inventory etc.

8 Digital Product Quality Digital product quality management systems for connecting 'traceability islands' back from customers to suppliers (root cause analytics)

7 Extended Supply Chain (near) real-time Monitoring Extended 'end-to-end' supply chain visualisation 'watch towers' for near real-time monitoring and decision making

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Digital Factory
Drivers

Business Drivers

1. Mass customisation
2. The need for flexibility & responsiveness
3. Real world variations

→

The Digital Factory

1. Digital Factory Design
2. Real-time Factory Scheduling
3. Flexible Factory Automation

Digital Factory
Meeting lean objectives

Lean Wastes	Flexible Factory Automation	Digital Factory Design	Simulation-based Factory Scheduling
Motion: Unnecessary movements by people	✓	✓	✓
Waiting: Wasted time waiting for the next step of the process	✓	✓	✓
Over production: Production before it is needed	✓		✓
Inventory: Excess products and materials not being processed	✓	✓	✓
Transportation: Unnecessary movements of products and materials	✓	✓	✓
Defects: Efforts caused by incorrect information ,rework and scrap.			✓
Over processing: More work or higher quality than is required by the customer			

Automation and variation
Sheep & beef processing

Background

- The introduction of robotics to the sheep processing industry had several goals:
  - Improve labour productivity,
  - Reduce repetitive strain injuries and cuts.
  - Reduce contamination of carcasses for the chilled lamb market.
  - Improve pelt quality.
- For sheep processing the challenges were complex because of a wide variety of carcass sizes and shapes, from light lambs at 20kg to aged rams at 75kg.
- New Zealand and Australia are the only two countries in the world which slaughter, process and export large numbers of lambs, and NZ is the world leader in this industry.
- The technology was initially developed at Industrial Research Limited (IRL) with funding from the Meat Research and Development Corporation in early 1990s and then extended in capability by industrial partners.
- Later IRL worked with a US beef processing company to apply the technology to that industry.

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Automation and variation
Sheep & beef processing

Y-cutting

- The initial project was for the Y-cutting operation. This is the initial slitting of the pelt to facilitate is removal. Unlike cattle, where the pelt is very robust, the sheep pelt is easily torn or damaged.
- A typical line speed is 8.5 carcasses per minute. The Y-cutting work utilises 3 operators to keep pace.

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Automation and variation
Sheep & beef processing

Y-cutting

- The robotic Y-cutter replaced the 3 operators. That gave a reasonable economic payback even with the very high robot costs of the day. There were also other important benefits from:
  - Reduced rework.
  - More consistent quality of carcasses.
  - Increased yield of quality pelts.
  - Improved carcass hygiene.
  - Better health and safety.

- Development was difficult:
  - Sensor systems, in the end mainly tactile, needed to be developed.
  - Commercial robot controllers were very difficult to communicate with to at the time, so we built our own robot.
  - The development of the cutting head was very important. Initially knives (some with force sensors) were used as with manual operations, but a mechanized cutter proved to be best.
  - The system needed to be “hardened”. The line and all equipment is washed with caustic solution and extremely hot water.
  - Development trials were difficult: Processing 10 carcasses in the lab is difficult. That is 1 minute and 25 seconds of production (0.3% of a shift) in the real world.
  - Workplace reception amongst workers was very good.

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Automation and Variation
Sheep & beef processing

Further commercial development

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Automation and Variation
Sheep & beef processing

Further commercial development

November 15, 2016 | Slide 11

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AGVs
First steps

- Easy to install and low cost.
- Operates like an urban train: Limited destinations on fixed routes following floor line.
- Reasonable productivity and payback but the number of tasks is limited.
- Requires considerable human interaction; typically load preparation and receiving load.
- Floor markings need maintenance.

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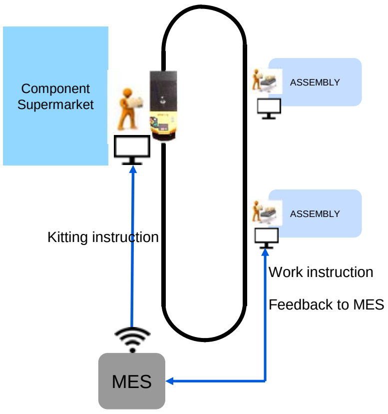
AGVs
First steps



AGVs
Next steps

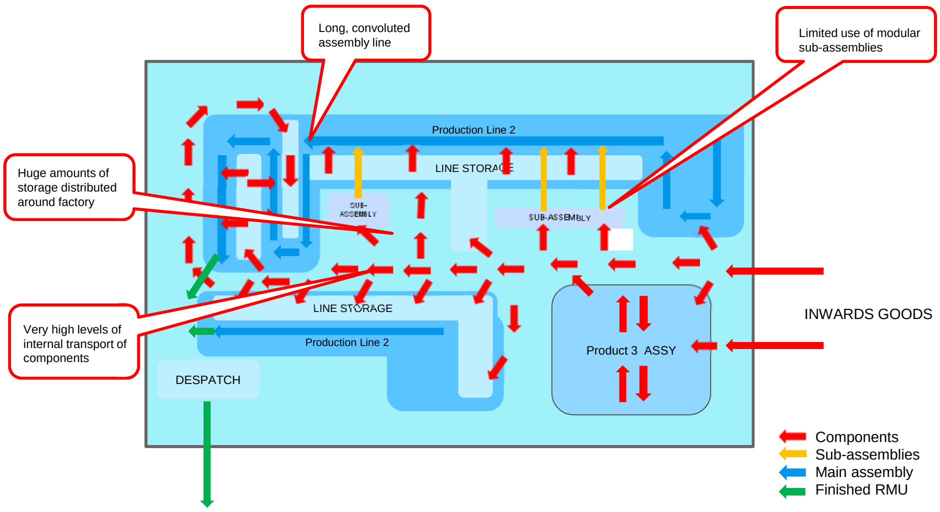
- Large, specialist heavy lifting AGV.
- Laser guided, flexible with many destinations.
- Typically no human interaction needed.
- Control system interacts with MES

AGVs
Future Factory:

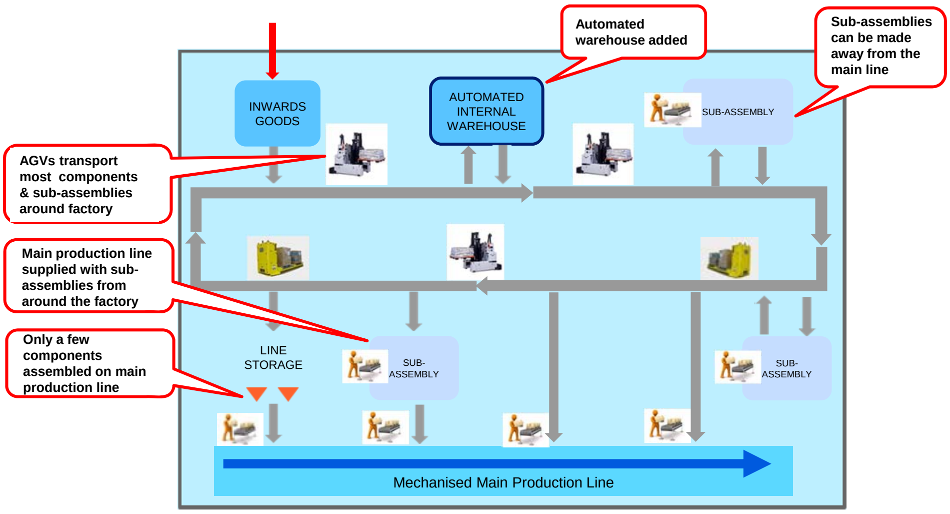
Factory A
- Distributed storage.
- Over 20 forklifts and drivers.
- Difficult workstation access on production line.
- Long, convoluted manual production line (not mechanized).

Factory B
- Current using forklifts and pallet trucks to move material.
- Relatively low level of control over internal transport
- 80+ km travelled per day using current methods.
- Manually intensive.

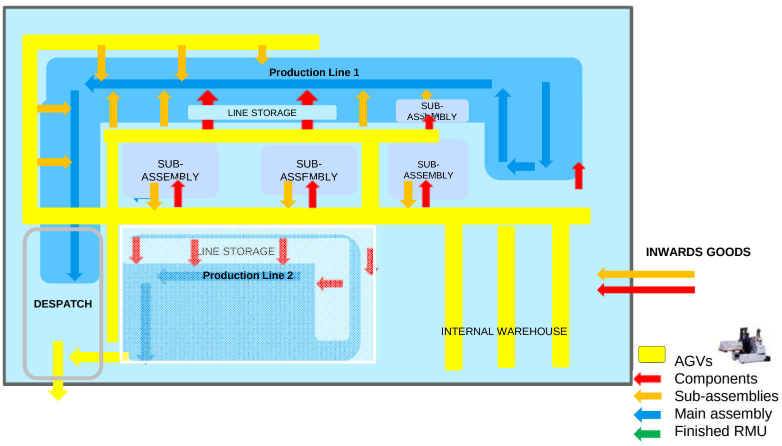
Future Factory
Situation 2014



Future Factory
Automated & Lean: Process



Future Factory
Automated & Lean: Block Layout & Flows



Future Factory
AGVs: First stage – internal transport

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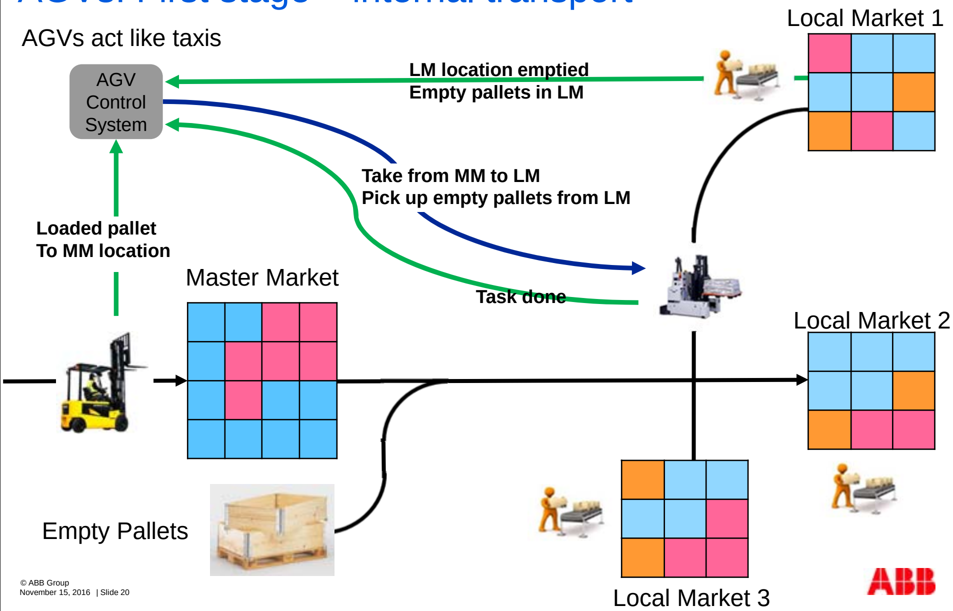
Future Factory
AGVs: First stage – internal transport

AGVs act like taxis



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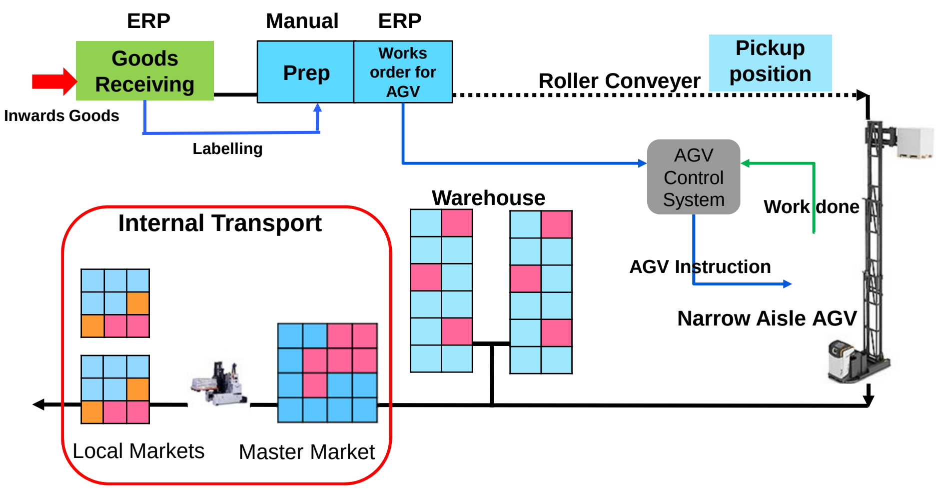
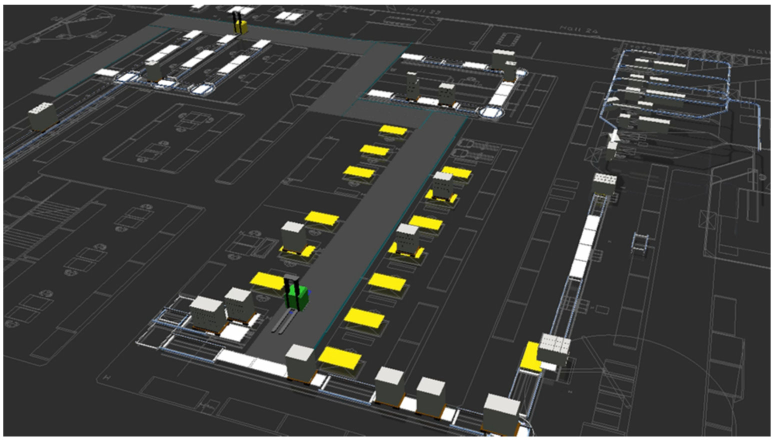
Future Factory
AGVs: Second stage - automated warehousing

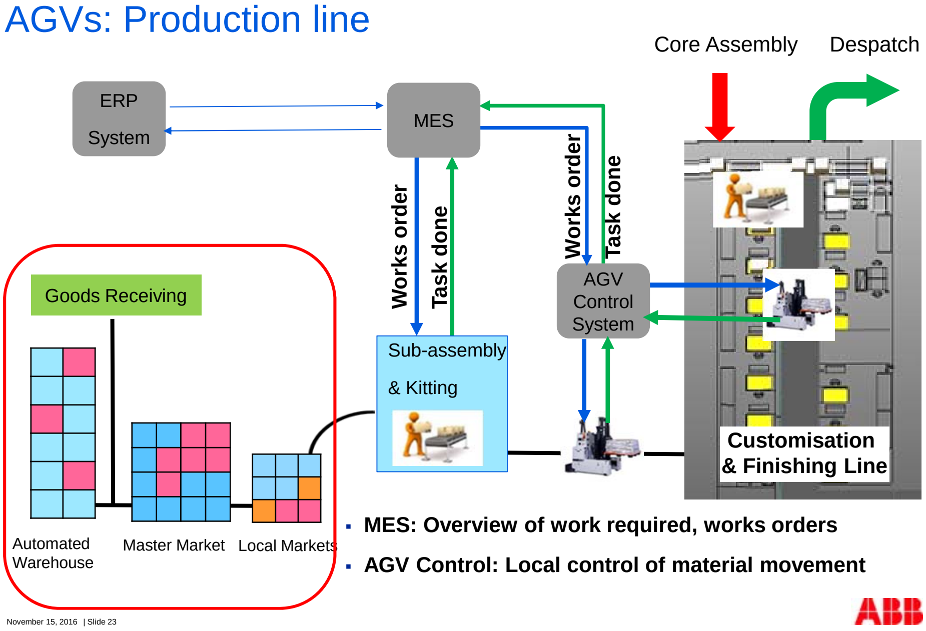


Future Factory
AGVs: 3D simulation of design of production line

- 3D simulation of the production line incorporates data on the variability of each task and machine.
- This produces a robust but economic solution (how many AGVs, workstations etc.).



Future Factory
AGVs: Production line



- **MES: Overview of work required, works orders**
- **AGV Control: Local control of material movement**

Digital Factories
Summary

- **Automation** is not always easy. Considerable innovation is required, particularly for production of variable products.
- The direct payback/investment return from **AGVs** is extremely good, particularly in high cost countries and for two or more shift operations.
- Indirect benefits of AGVs include:
  - Less downtime for assembly line staff from: Correct parts in the correct place at the right time.
  - Lower inventory.
  - HSE improvements.
  - Floor finishes last longer.
  - Decreased product and part damage.
  - Easy to vary production rate, add capacity, change equipment, and change the layout or process.
- AGVs require improved, better defined factory organization, which in turn has spill-over benefits to shop floor management and practices.
- **3D simulation** that incorporates variability is very effective in production system design.
- **Next steps**. Use 3D simulation for risk based production scheduling:
  - By running multiple scenarios with variability a robust but economic schedule can be found.
  - This is superior to the usual Advanced Production Scheduling (APS) which assumes full information and deterministic data with no variations (and is therefore fundamentally optimistic).

Power and productivity
for a better world™

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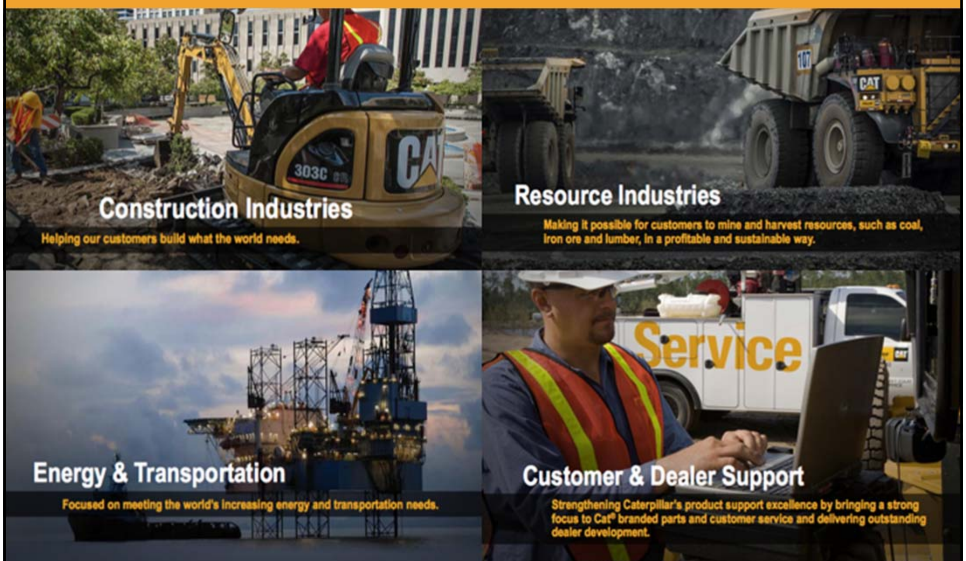
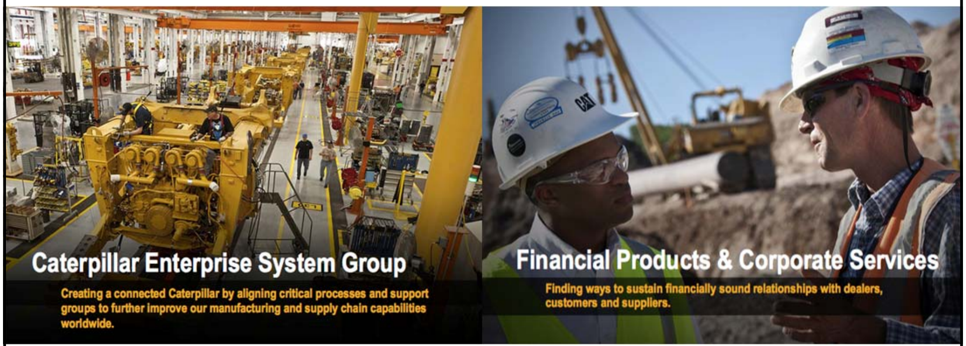
Practical S&OP Challenges for Integrated Manufacturing Networks

Haydn J. Powell
Supply Chain Strategy Manager,
Advanced Components Manufacturing
Caterpillar Inc.

Caterpillar Inc.



Caterpillar Inc.



Centralized Support and Planning Functions

CATERPILLAR® ADVANCED COMPONENTS MANUFACTURING 3

Complexity

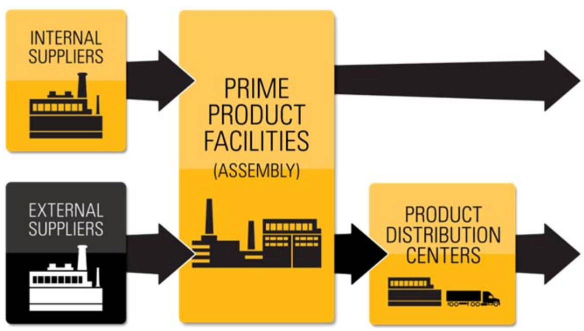
Global Scale and Size

CATERPILLAR® ADVANCED COMPONENTS MANUFACTURING 4

Manufacturing and Supply Network

CATERPILLAR® ADVANCED COMPONENTS MANUFACTURING 5

Caterpillar's Legacy Supply Chain



- Focused on Supply.
- Limited Understanding of Customer Service Requirements

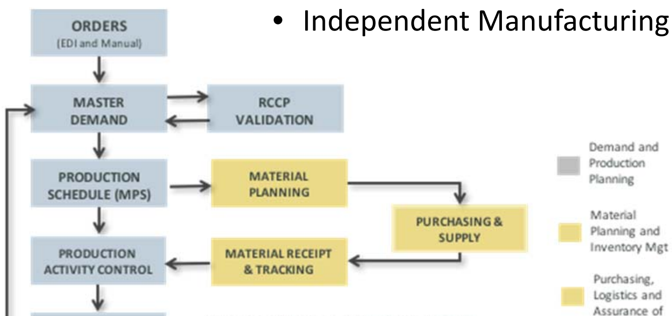
CATERPILLAR® ADVANCED COMPONENTS MANUFACTURING 6

Caterpillar's Engineered Supply Network

- Holistic Planning, Customer Connectivity
- Network
- End-to-end Optimization

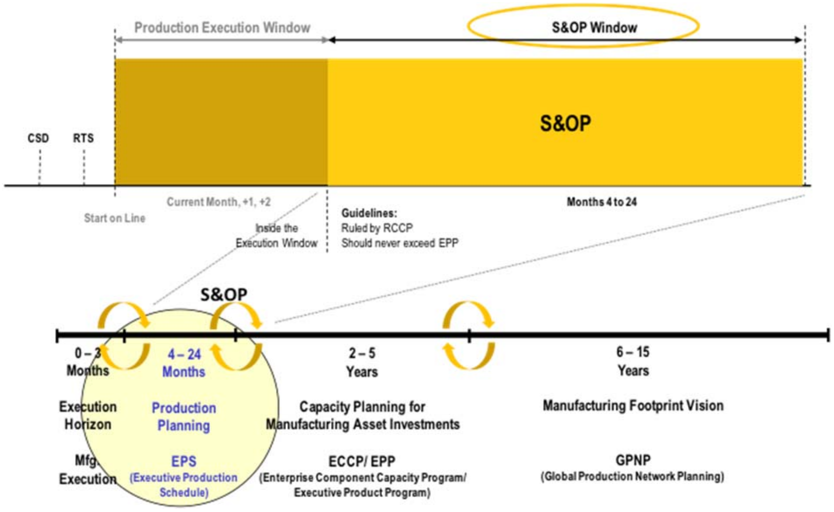
Integration Complexity

- Mostly Dependent Demand
- MRP II Operating Model
- Independent Manufacturing Facilities



Simplified Schematic of the MRP II Operating Model

Planning Horizons



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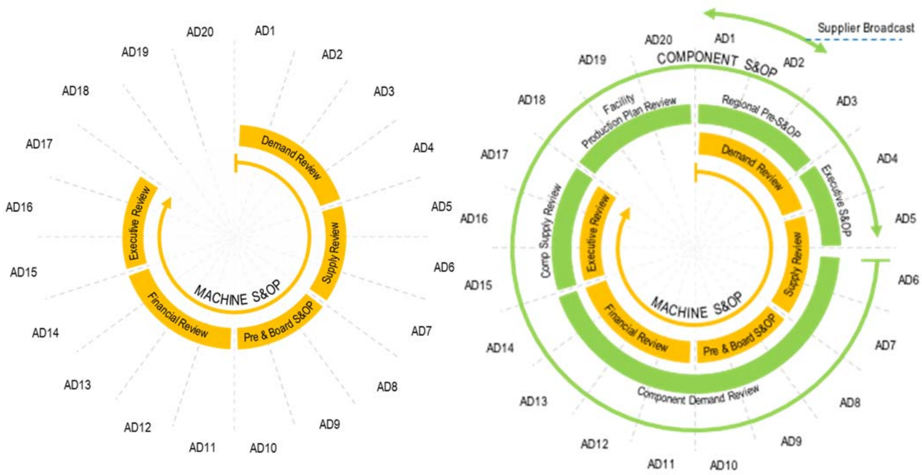
S&OP Cycle



CATERPILLAR® ADVANCED COMPONENTS MANUFACTURING 10

Maturity Model

Gen III

Scenario-driven Business Planning

- Ability to evaluate alternate plans and choose the most cost effective supply plan
- Integration of upstream demand and downstream capacity confidence intervals

Gen II

Streamlined Decision-making

- Effective participation with clarity on RACI;
- Financial impact assessment allows structured decision-making; timely issue escalation & resolution

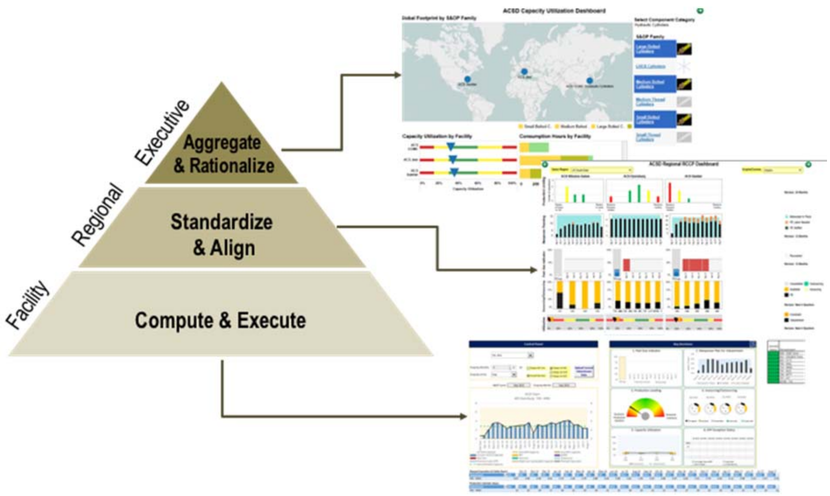
Gen I

Fundamentals of S&OP

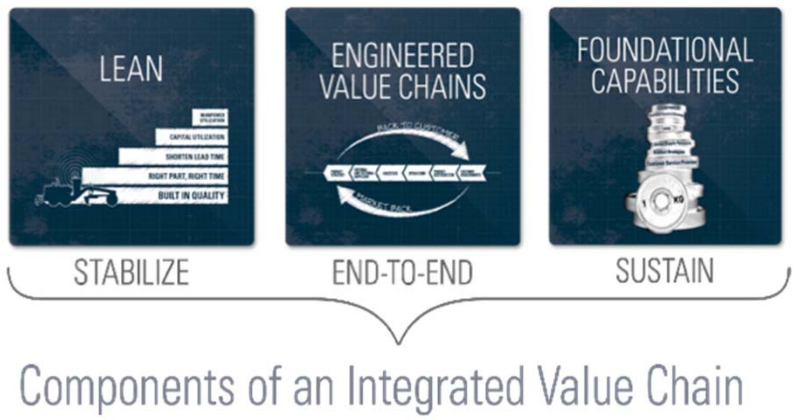
- Monthly review of component demand; component supply plan; and facility production plan;
- Measurement of production plan conformance and supporting RCCA

Legacy Challenge - Standardization

Integrated Approach



Integrated Value Chain



Discussion – Questions

They've picked it before you've clicked it

Supply chain digitilisation in B2C and its implications for customers and organisations

Catherine McDermott

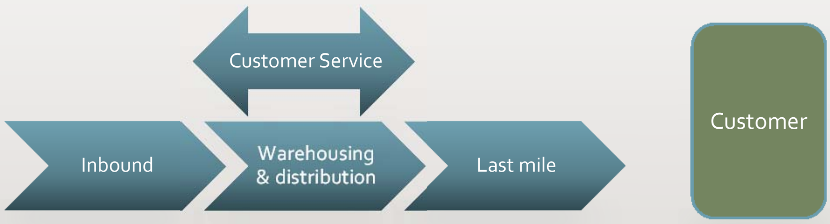
- IfM Alumni, chartered mechanical engineer
- Worked in operations and supply chain for over 25 years
- Led operations in a number of large retailers
- Been on the journey from "bricks & mortar" to "omnichannel"

Iceland Argos amazon TESCO celesio LloydsPharmacy

Impact of Digitilisation

- How is digitilisation changing the supply chain in B2C businesses to better serve the customer?
- What are the characteristics of organisations that are doing this successfully?
- Are there any implications for customers and the wider community?

Changes to the supply chain in B2C



Customer service (CS)

India
South Africa
Costa Rica
Philippines

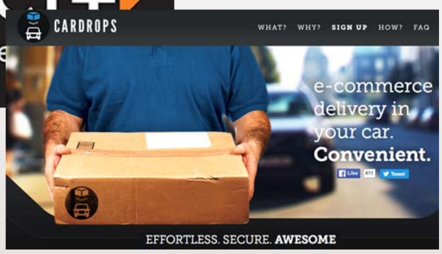
Digitalised CS

Last mile

waze
OUTSMARTING TRAFFIC, TOGETHER

Digitalised last mile

click & co
collect+
parcels made e



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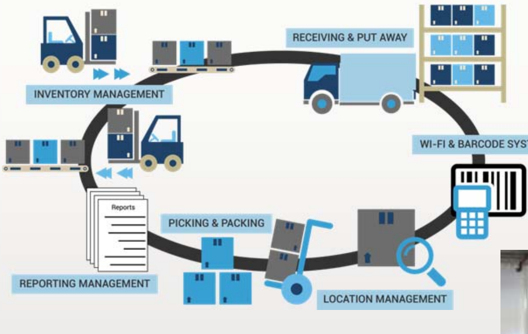
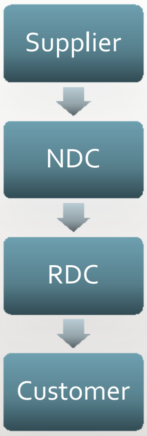
Warehousing & distribution

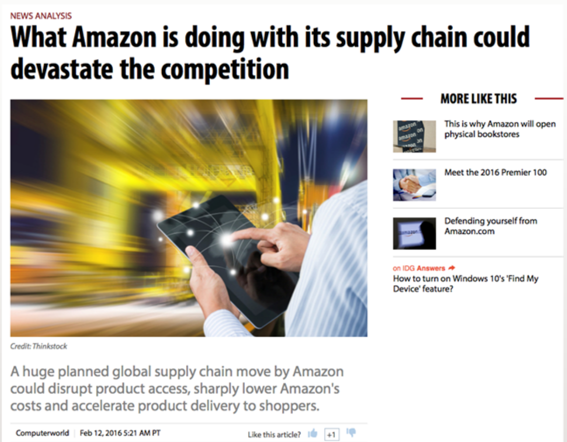


Digitalised warehousing & distribution

Inbound & Inventory



Digitalised Inbound



NEWS ANALYSIS

What Amazon is doing with its supply chain could devastate the competition

MORE LIKE THIS

This is why Amazon will open physical bookstores

Meet the 2016 Premier 100

Defending yourself from Amazon.com

on IDG Answers

How to turn on Windows 10's 'Find My Device' feature?

Credit: Thinkstock

A huge planned global supply chain move by Amazon could disrupt product access, sharply lower Amazon's costs and accelerate product delivery to shoppers.

Computerworld | Feb 12, 2016 5:21 AM PT | Like this article? +1

Digitalised Inbound & Inventory

Mercedes-Benz

What are the characteristics of organisations that are doing this successfully?

People

- Skills Profile
  - Fewer generalist managers and more, highly skilled specialists particularly with engineering and technical skills
- Different Mindset
  - See technology as the solution not the limitation
  - Prepared to think differently – "how do I?"
- Pace and adaptability
  - Move fast: not afraid to try (and fail)
  - Aren't afraid of their own future:
    - expect to do different jobs requiring new skills
    - expect change so don't protect the status quo

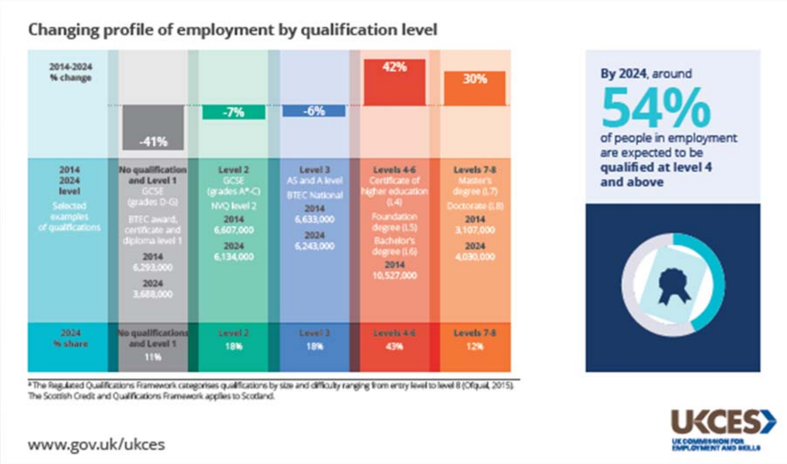
Organisation

- Substance over form
- Have a long-term vision of what can be achieved
- Different attitude to communication
- Pace and adaptability
- Think enterprise wide not just supply chain
- Always come back to processes that add value for the customer

Are there implications for customers and the wider community?

Incredible convenience and quality available at low cost

Impact on skills needed



Nature of privacy & autonomy

Vulnerability of infrastructure

Resource Efficiency

Supply Chain Digitilisation

- Digitilisation is already changing all aspects of the supply chain in B2C businesses
  - Customer Service
  - Last Mile
  - Warehousing & Distribution
  - Inbound
- Organisations that are doing this successfully are different from traditional retailers in their people and how they are organised
- These changes have implications for customers/wider community that we need to understand and either consciously embrace or legislate for.

IKEA Industry

Supply Chain of the future

IKEA Industry

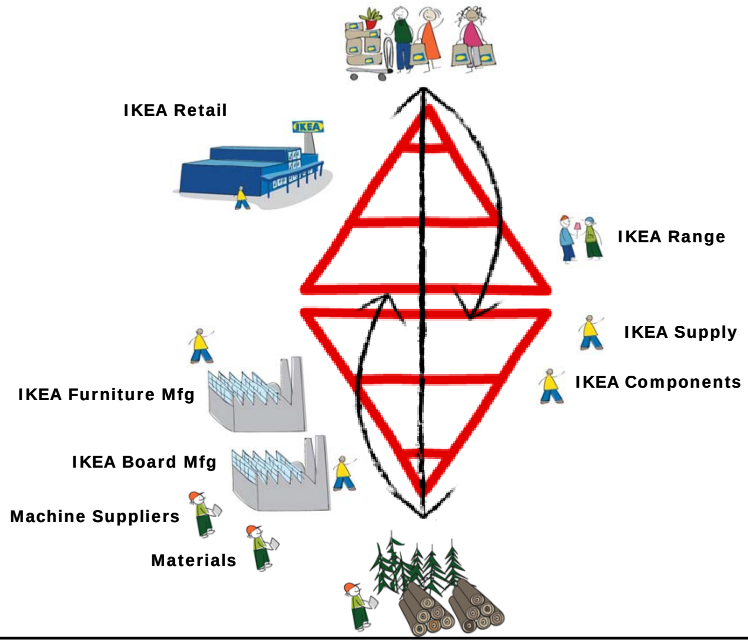
IKEA Industry in the world

40 production units in 10 countries
China, France, Hungary, Lithuania, Poland, Portugal, Russia, Slovakia, Sweden, and the US

19 000 co-workers

Top 5 production countries
Poland, Russia, Slovakia, Portugal and Sweden

Optimized Value Chain



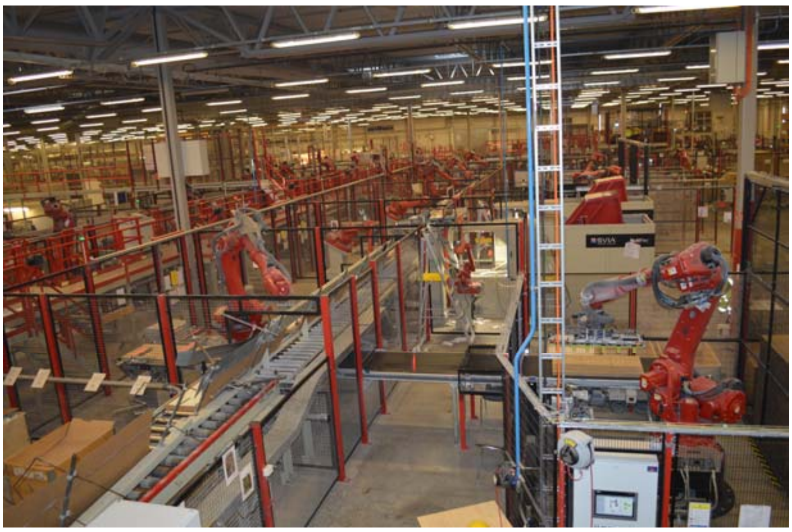
What have we been up to?

1992-2008 The Early Years

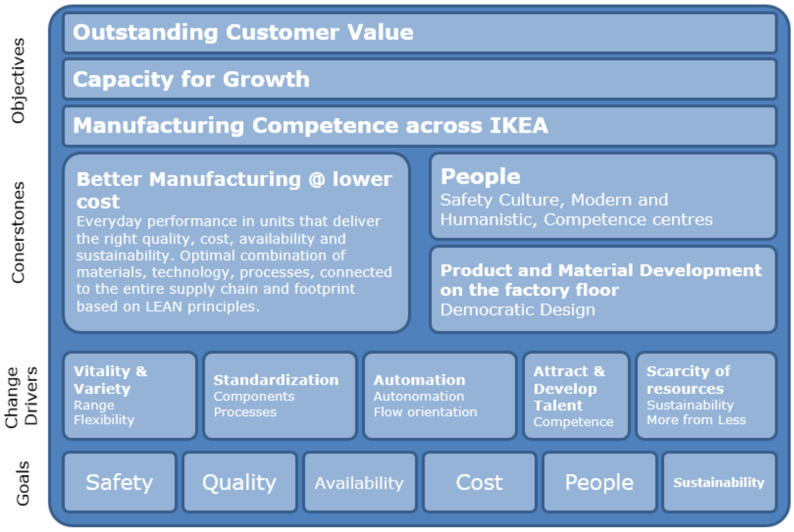
1998 Operator	Manufacturing Execution Systems
2002 Argos	Vision System
2002	MES data in i ERP
2006 Arena	Simulation
2009	Device Integration Platform
2013 M3	ERP Global Model

Blue Print
Supply Chain Project

2008 Hultsfred 3.0



2013 Manufacturing Strategy



Manufacturing Strategy

Manufacturing Strategy: What to produce and how to produce it.

We have a 7 area approach that will help transform our manufacturing activities for the future needs.

The areas are,

- Areas of activity: Buy or Make
- Vertical Integration: Make or Buy
- Plant, Process and Equipment
- Material, Product Development and Engineering
- People
- Capacity, Planning and Logistics
- Knowledge Transfer

Plant, Process and Equipment

- **Plant roles and networks.** Different reasons in different segments and markets
- **Connection to footprint.** Tailor plant, process and equipment to footprint
- **Growth – capacity and standardisation.** New capacity according to our technical standards
- **Flexibility – range, vitality and batch**
- **Quality** – In every process step
- Standardized **Automation** solutions
- **Maintenance** - preventive

Capacity, Planning and Logistics

Capacity:
- We favour **lead** over **lag** capacity **demand** principles.
- We identify capacity gaps through the **strategic plan**.

Planning:
- The starting point is always the **customer need**
- We have **ONE** aligned **end-to-end plan**
- **Deviations** will be handled through visibility and by monitoring real-time information.

Logistics:
- The flow of material and information will be **integrated** between stakeholders in the flow. We will **not pass on poor** quality of product or information.
- We will be able to **trace** products on batch level throughout the flow.

Knowledge Transfer

IKEA possesses knowledge within the area of manufacturing valuable for the development of other IKEA processes as well as IKEA suppliers. IKEA will make this knowledge available by being open and transparent as well as sharing best practice.

General Manufacturing and Production Concepts

We will offer available resources to support and develop IKEA as well as IKEA suppliers within the fields of LEAN, Safety, Quality and Sustainability.

Specialist Knowledge

We will, through our competence centers, make specialist competence available to support and develop category strategies and IKEA Suppliers.

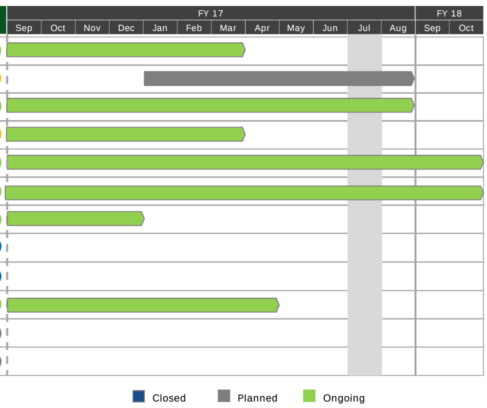
Training and Education

We will support and develop IKEA learning initiatives within areas of general manufacturing as well as specialist knowledge

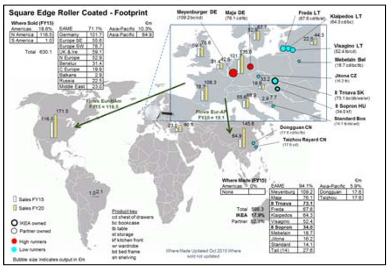
Manufacturing Strategy Inititives

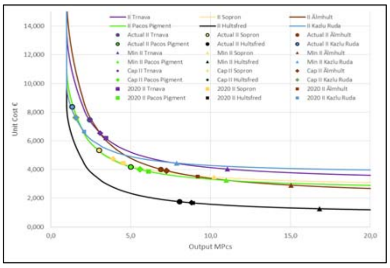
Master Plan – Approved Projects Financed Centrally, 1st Wave

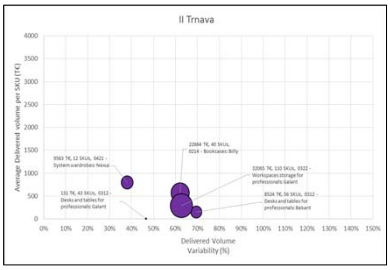
Description	Project Owner	Project Manager	Sts
Plant Roles and Networks	Leif H	Per B	
Connect Processes to Footprint	Per B	Per D	
Virtual Manufacturing	Per B	Rozle P	
Goal and Action alignment	Örjan J	Magnus S	
MOM: Manufacturing Operation Management	Per B	Filip B	
SFA: Standardized Flexible Automation	Per B	Per D	
Standardized Plant organization	Anders S		
Build DFx capability	Per D	Tobias A	
Build Mixed Material capability	Per D	Tobias A	
Systems supporting Product/Material development	Per D	Tobias A	
-		-	
		-	



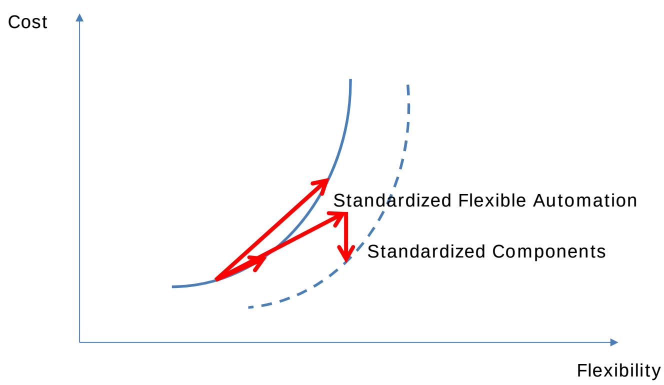
Strategic Initiative: Plant Roles and Networks



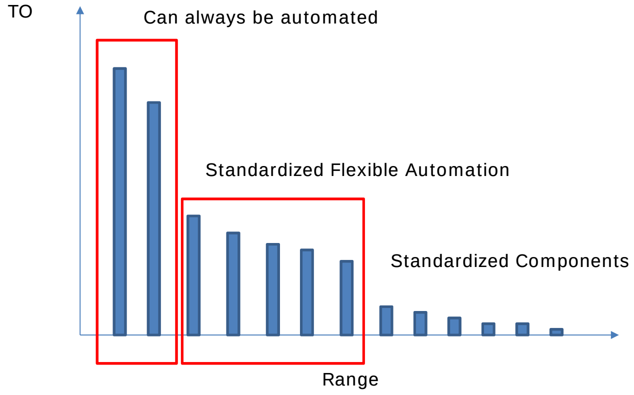




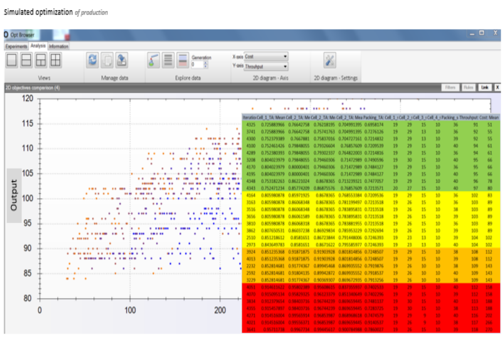
Strategic Initiative: Standardized Flexible Automation



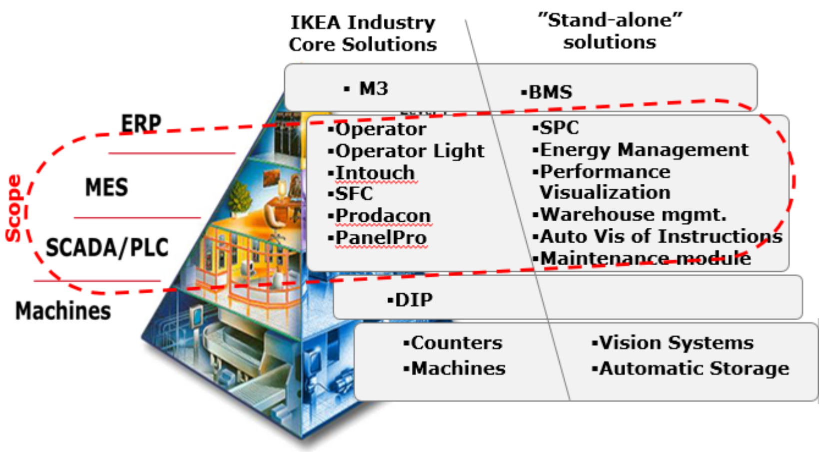
Strategic Initiative: Standardized Flexible Automation



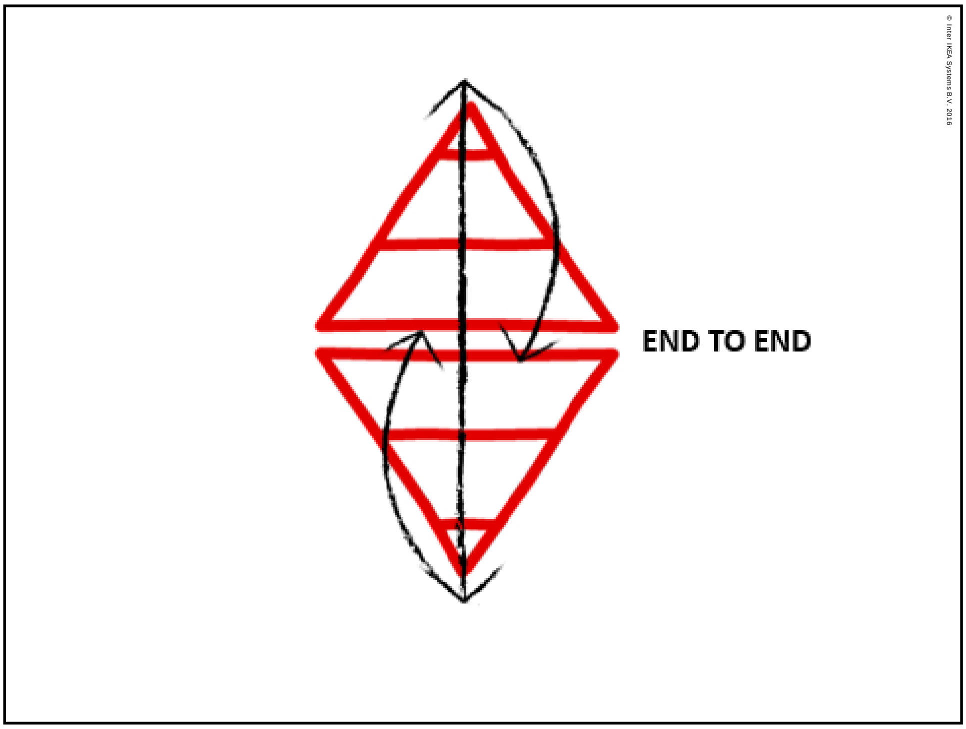
Strategic Initiative: Standardized Flexible Automation & Virtual Manufacturing



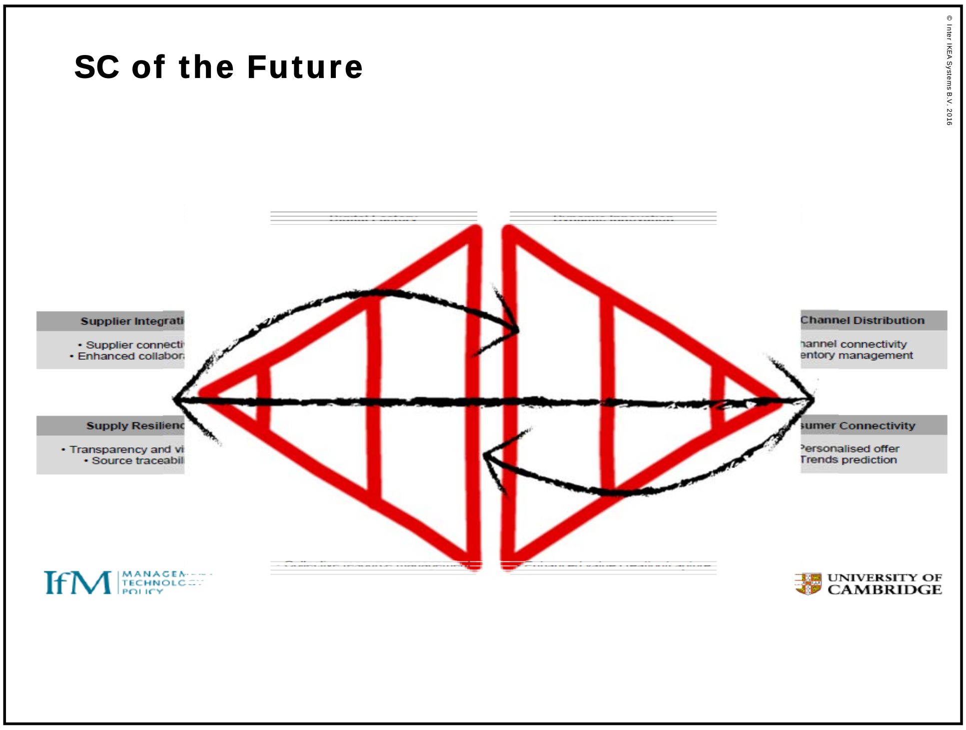
Strategic Initiative: Manufacturing Operations Management



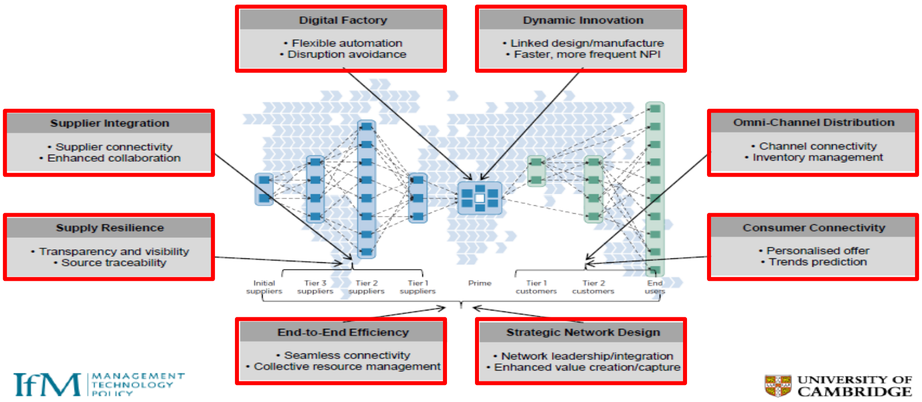
What's next?



SC of the Future



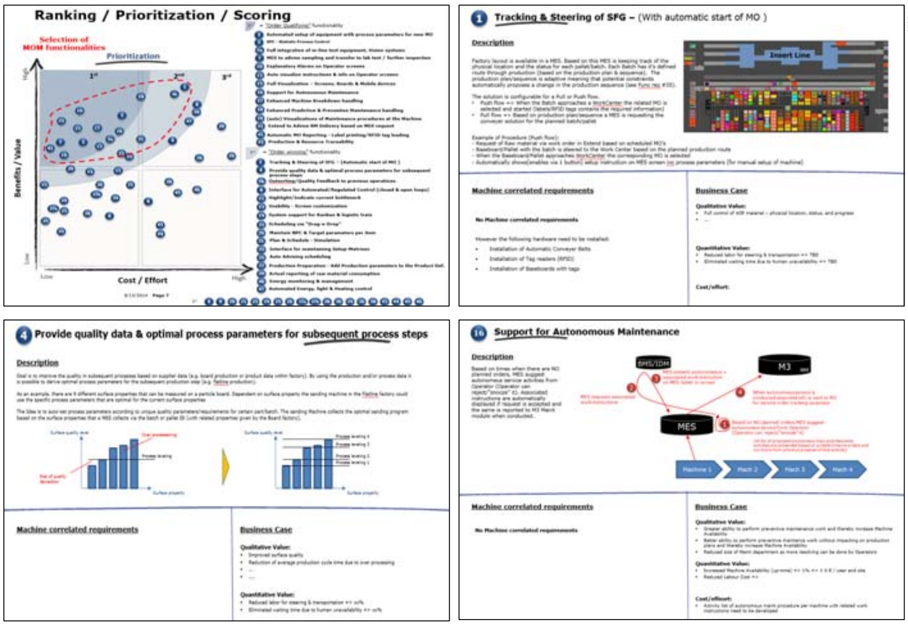
SC of the Future



IfM MANAGEMENT TECHNOLOGY POLICY

UNIVERSITY OF CAMBRIDGE

SC of the Future



Thank you!

Questions?

Per.Berggren@ikea.com

Wavin Group perspective on Digitization

Richard VAN DELDEN

Executive Director Supply Chain & Operations

Mexichem
Building & Infrastructure

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Content

- Introduction Wavin Group
- Digital Network Design
- BIM-Revit
- Robotisation (Cobots) using Universal Robots
- Where Next for Digital Supply Chains?

Introduction Wavin Group

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Facts & figures Wavin Group

Active in 25+ countries

€ 1.2 bn in revenues in 2014

Over 5,500 employees

Established in 1955

Wavin is part of the Mexichem Group

wavin

Mexichem

A global leader in plastics pipe systems and the chemical and petrochemical industry

Active in 90+ countries globally

Over $5.6 bn in annual revenues

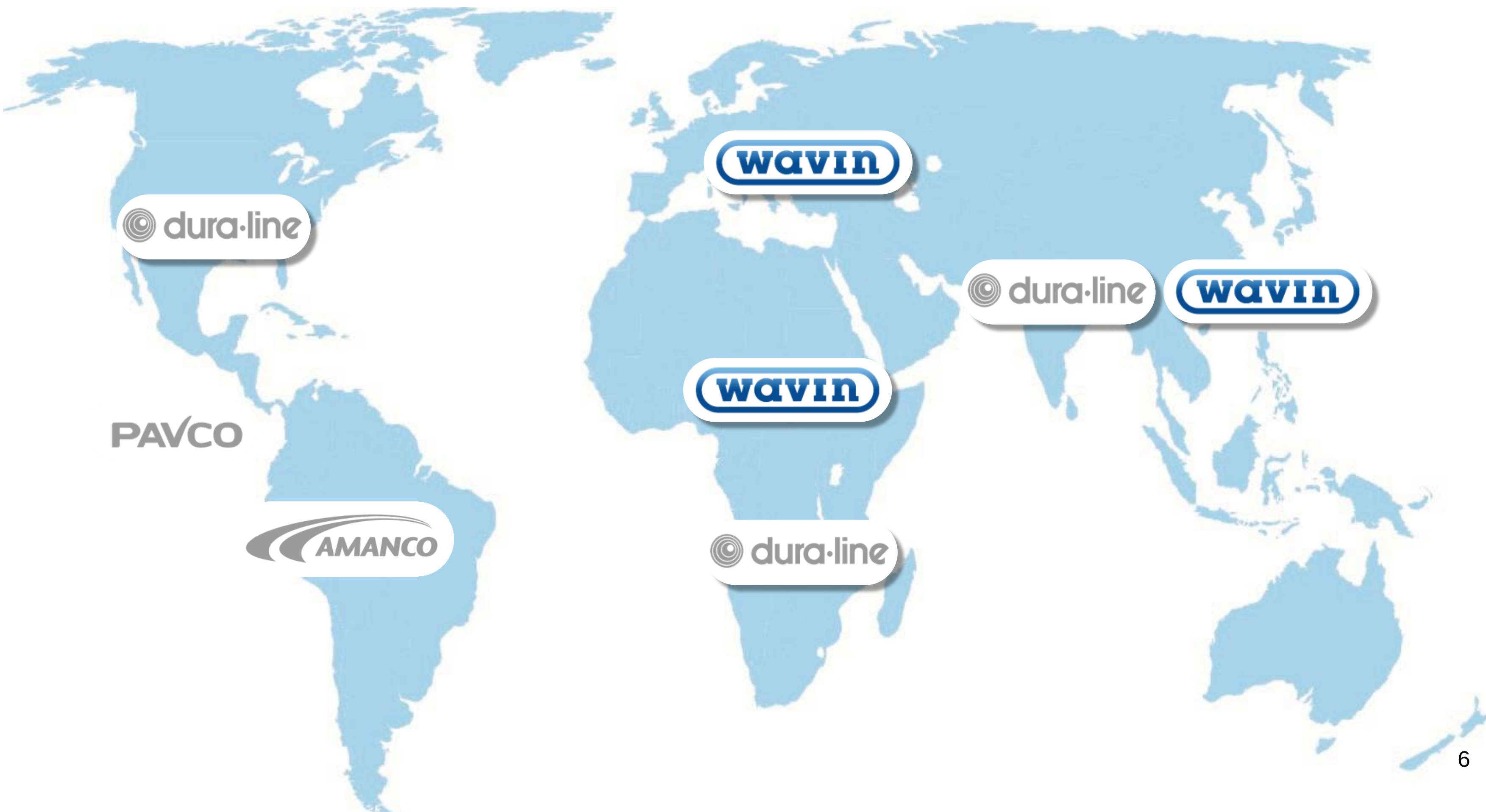
Over 19,200 employees

Based in Mexico city

Mexichem Fluent pipes & fittings business

wavin

Mexichem

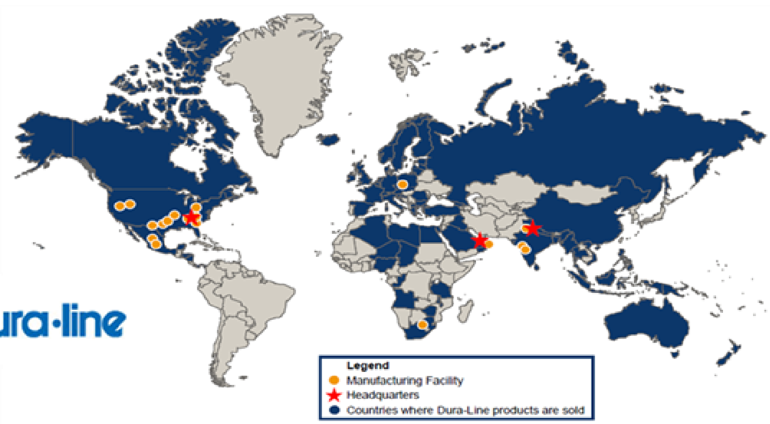


Mexichem Fluent market positions

Amanco Brand	Wavin Brand	Dura-line Brand	Mexichem Fluent
13 countries	26 countries	40 countries	52 countries
729 production lines	620 production lines	159 production lines	1,558 production lines
670 kMt capacity	568 kMt Capacity	502 kMt Capacity	1,740 kMt Capacity
24 manufacturing sites	22 manufacturing sites	18 manufacturing sites	64 manufacturing sites

Market Position	
Argentina	#1
Colombia	#1
Ecuador	#1
El Salvador	#1
Guatemala	#1
Honduras	#1
Mexico	#1
Peru	#1
Panama	#1
Venezuela	#1
Brazil	#2
Costa Rica	#2
Nicaragua	#2

Market Position	
Czech Rep.	#1
Denmark	#1
Hungary	#1
Italy	#1
Ireland	#1
Netherlands	#1
Poland	#1
UK	#1
Baltics	#2
Norway	#2
Sweden	#2
Belgium	Top 3
France	Top 3
Romania	Top 3
Turkey	Top 3
Germany	Top 5



Digital Network Design

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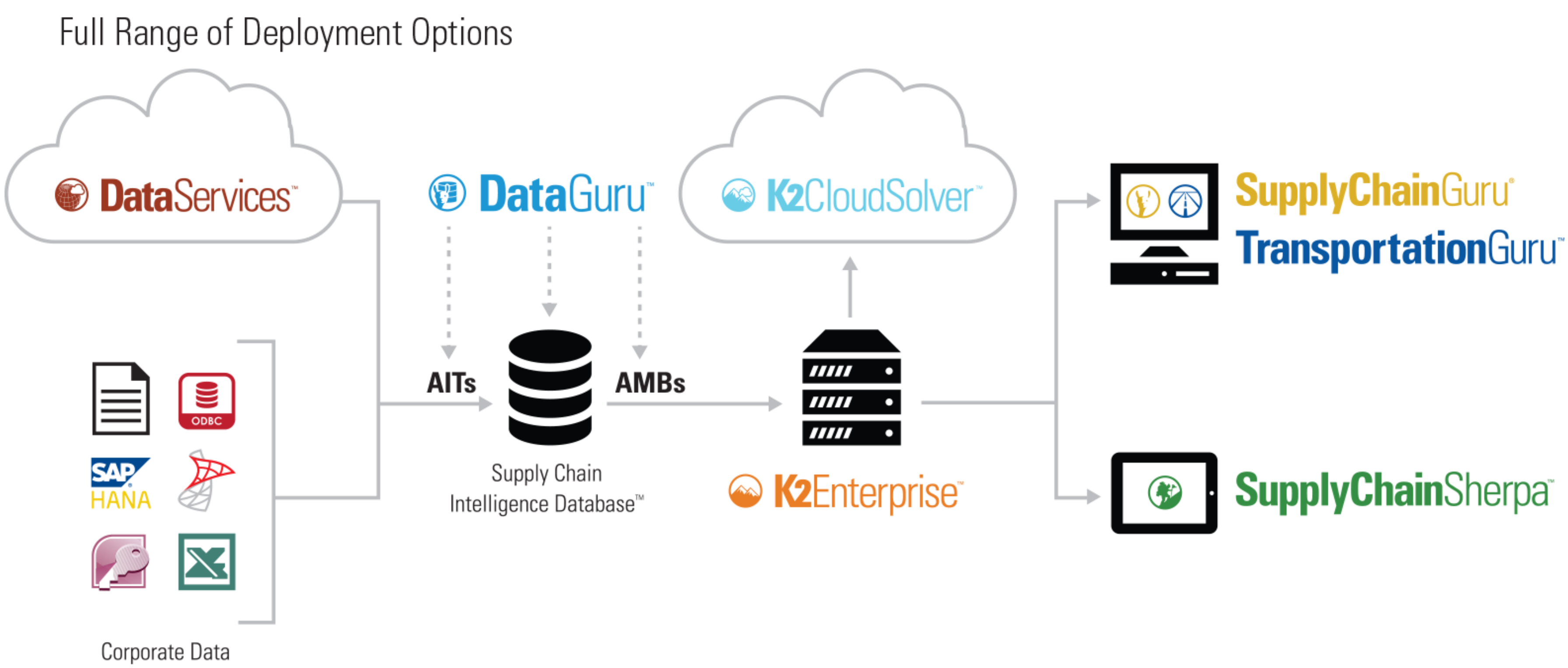
LLamasoft Product Overview

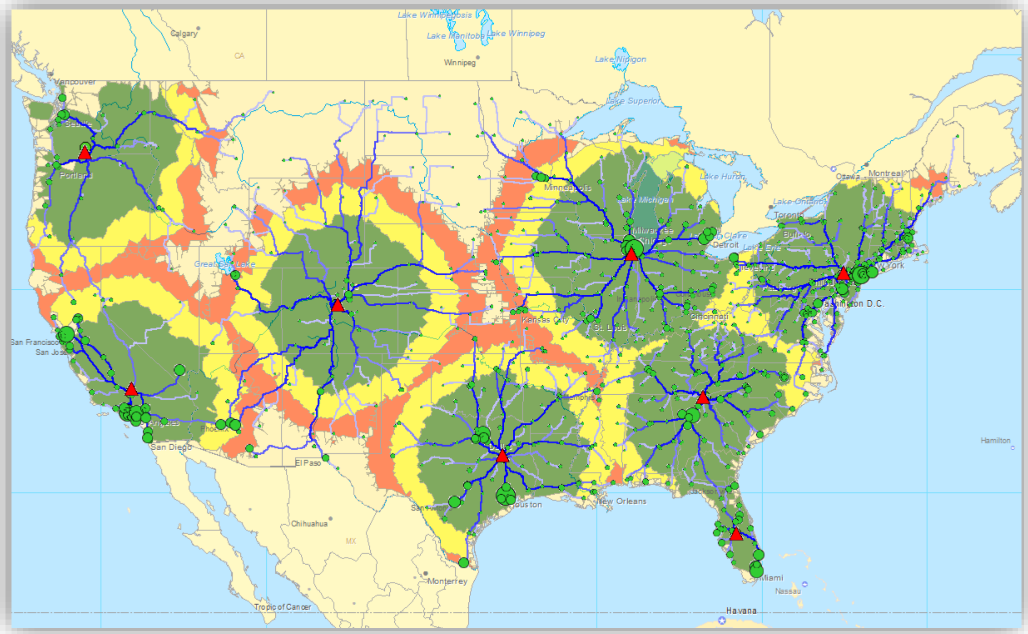


LLamasoft®
Supply Chain By Design

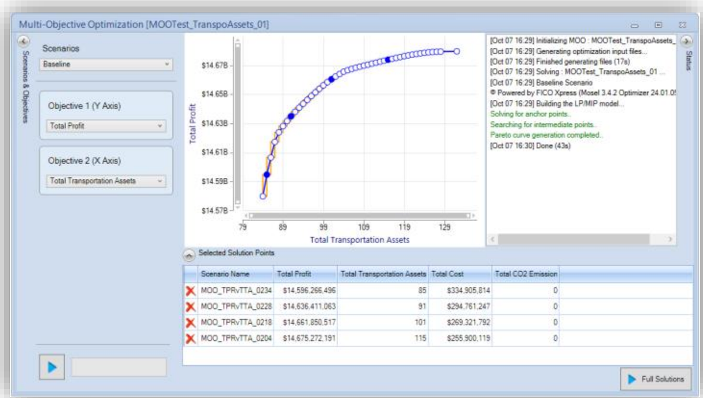
Supply Chain Guru

Model, Optimize, Simulate Your Supply Chain

- Visually Rich Integrated Environment for Designing Supply Chains



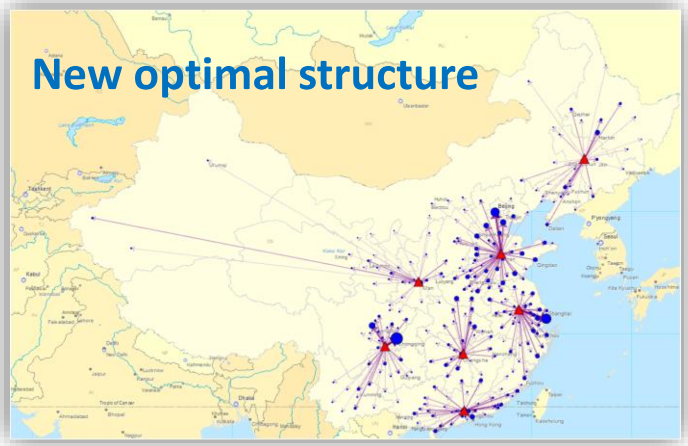
- Design Engine Encapsulating Multiple Solvers



LLamasoft®
Supply Chain By Design

Network Optimization

- End-to-end model from tiers of suppliers to the customer
- Detailed modeling of complex production processes, BOMs, multi-time period capacities, road routes, etc.
- Comprehensive constraint modeling
- Fastest solve times on the largest models

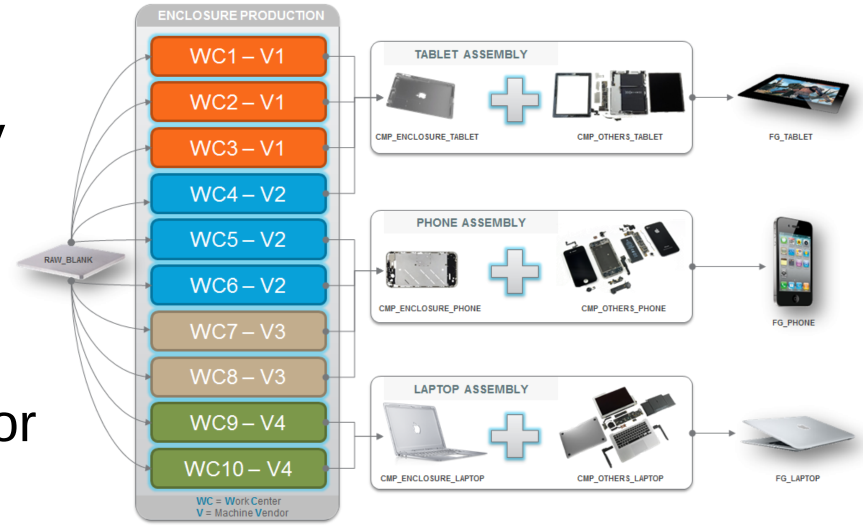


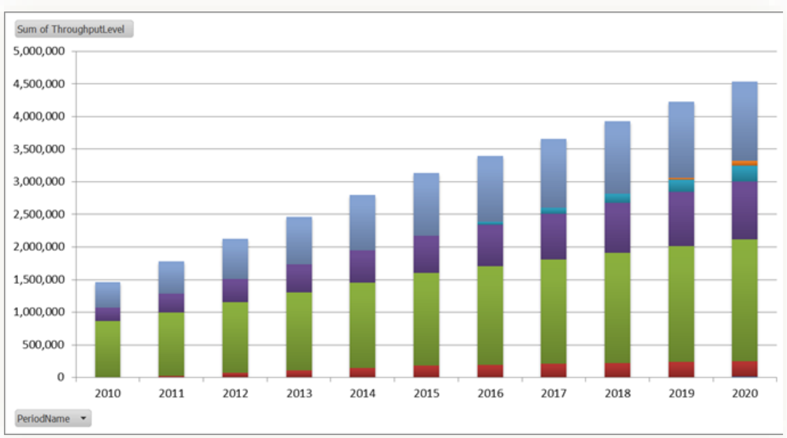
Llamasoft® Supply Chain By Design

Production Footprint Optimization

Detailed Modeling of All Production-Related Processes and Capacities

- Platform for optimizing both production capability and capacity at a detail level
- Balances production capacities globally and within each facility
- Optimize for maximum utilization or highest margin (max profit)
- Supports S&OP modeling for near-term realignments
- Primary Benefits
  - Optimally align forecasts with production footprint
  - Rebalance production capacities based on short term changes in demand



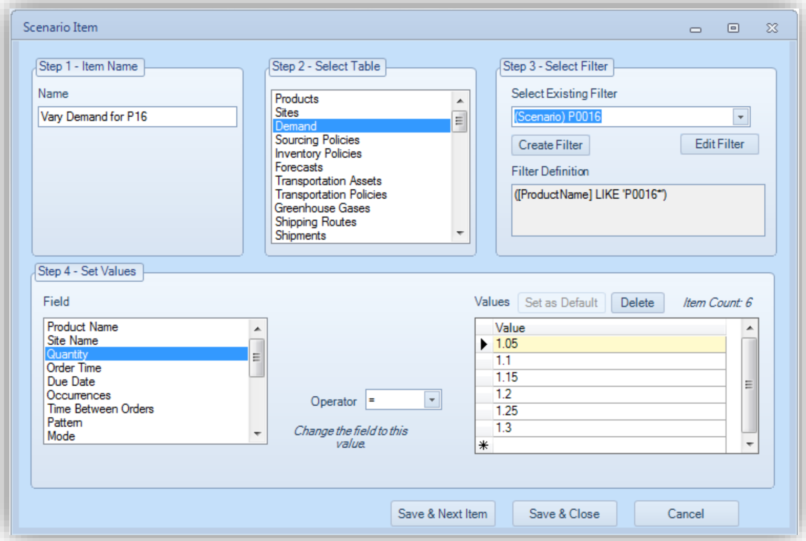


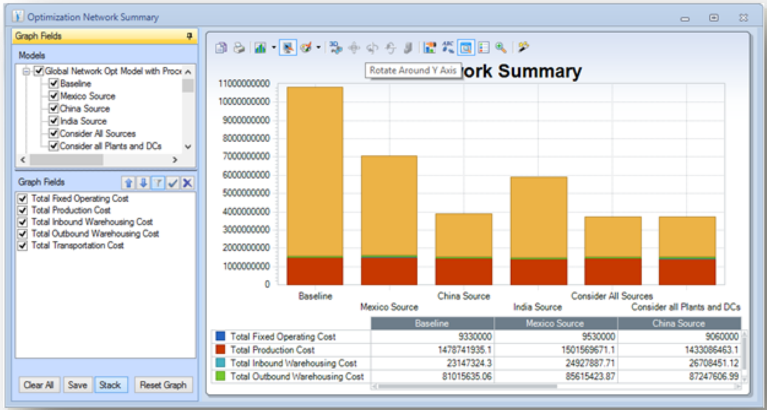
LLamasoft® *Supply Chain By Design*

Scenario Management

Create Multiple Scenarios within a Single Model

- Generate sensitivity ranges around key costs, capacities, demand characteristics, etc.
- Self-documenting audit trail of all scenario changes and definitions
- Compare all scenarios side-by-side in graphs, maps and reports
- Data updates to the baseline propagate through all scenarios





LLamasoft®
Supply Chain By Design

Project objectives & approach UK Distribution

In the UK distribution project we aimed to reduce the plastic freight cost by improving the shipment load factors. The average load factor for plastics is currently 2.1 ton, this is less than 60%. Wavin UK aims for an average load of more than 2.5 ton.

To reach the objective we analyzed the current situation and the planned changes from July 1st 2016. We developed an optimization model to estimate the effect of changes to the transportation network.

Three scenarios are defined focusing on the effects of specific changes. The forth scenario combines the results of these scenarios and uses customer segmentation and geographical characteristics to come to an overall solution.

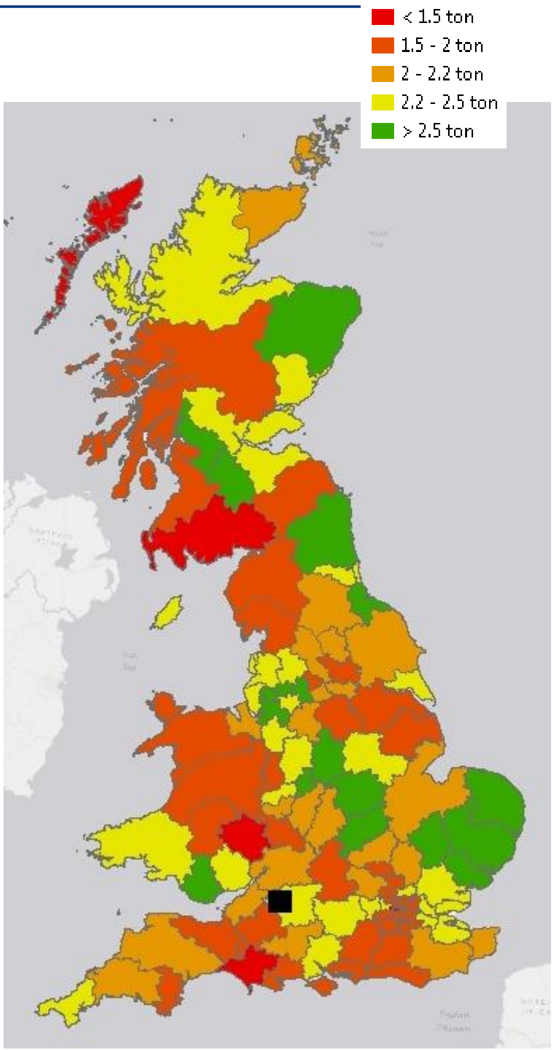
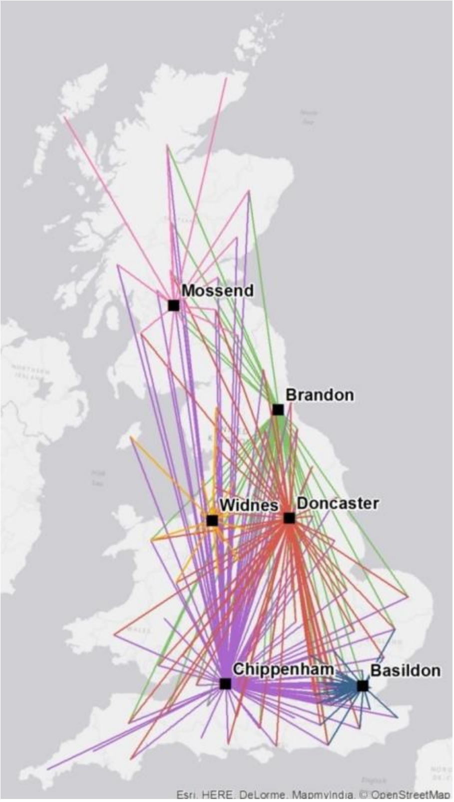


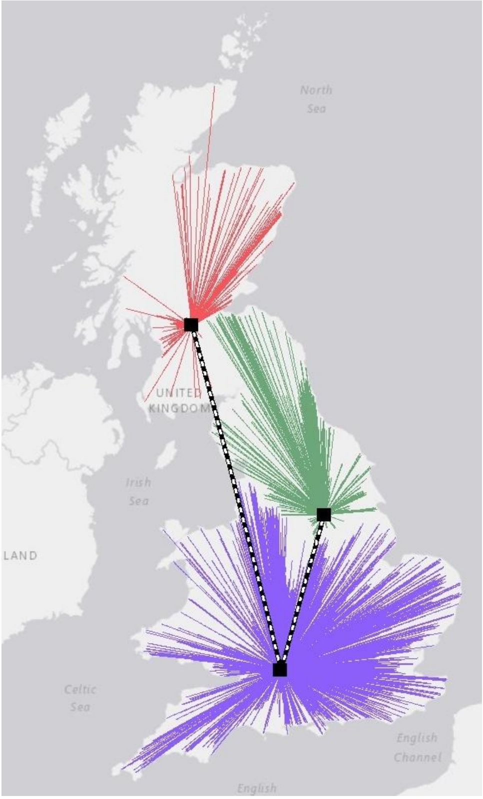
Figure: Current average load factors per area

Base case 2015 and reference 2016 compared

In the reference model 2016 there are the following changes compared to the current situation in represented in the base case 2015:

- No more cross docking
- No more radials from Widnes, Brandon, and Doncaster
- Reduced core fleet (from 67 to 38 vehicles)





BIM-Revit

Mexichem Building & Infrastructure

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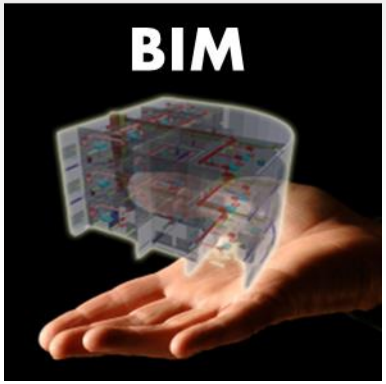
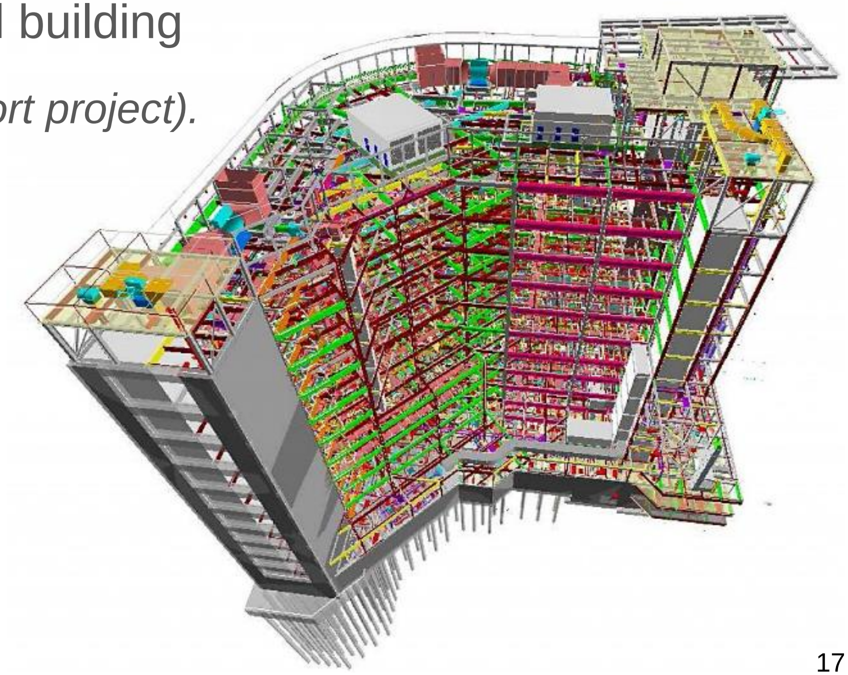
What is BIM?

BIM =

Building	mainly **Building** projects,
Information	digital **Information** of the project,
Modelling	the information is linked to a digital 3D **Model** of the actual building
	(one family house to airport project).





Advantages of BIM versus CAD designs

Ambitious objectives issued by the British Government resulting the BIM way of working.

Lower costs

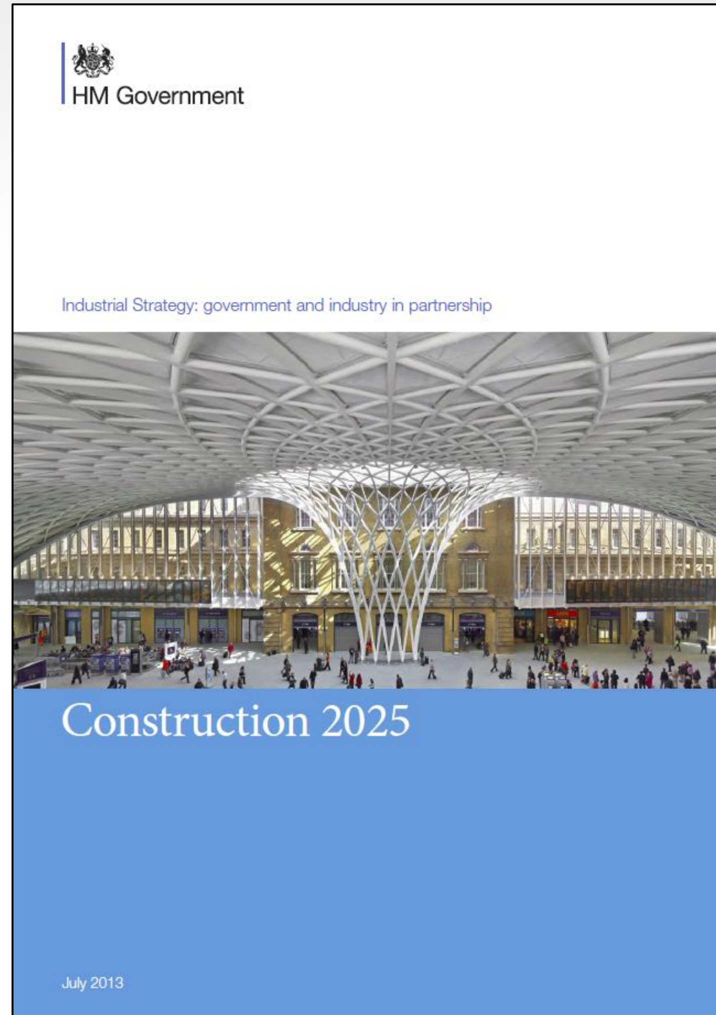
33%

reduction in the initial cost of construction and the whole life cost of built assets

Faster delivery

50%

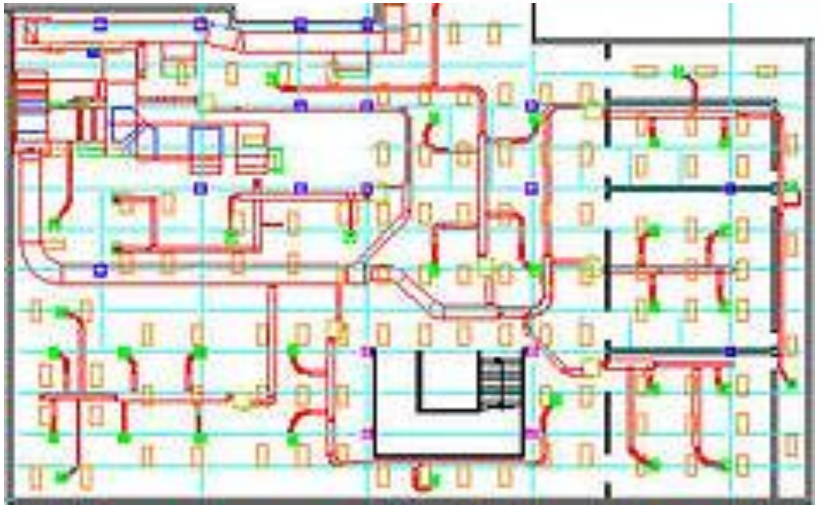
reduction in the overall time, from inception to completion, for newbuild and refurbished assets

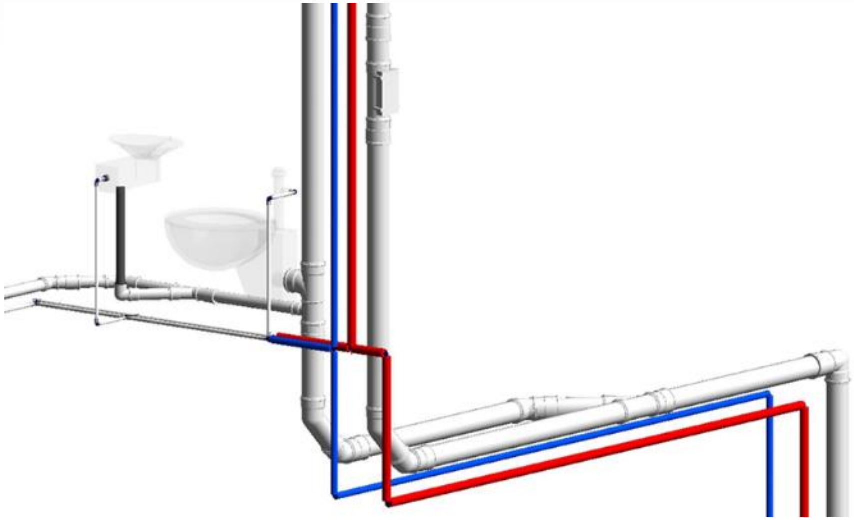


BIM way of working is replacing CAD

From 2D CAD design

To 3D BIM design





Example video on Reducers in Wavin Revit packages

Robotisation (Cobots)

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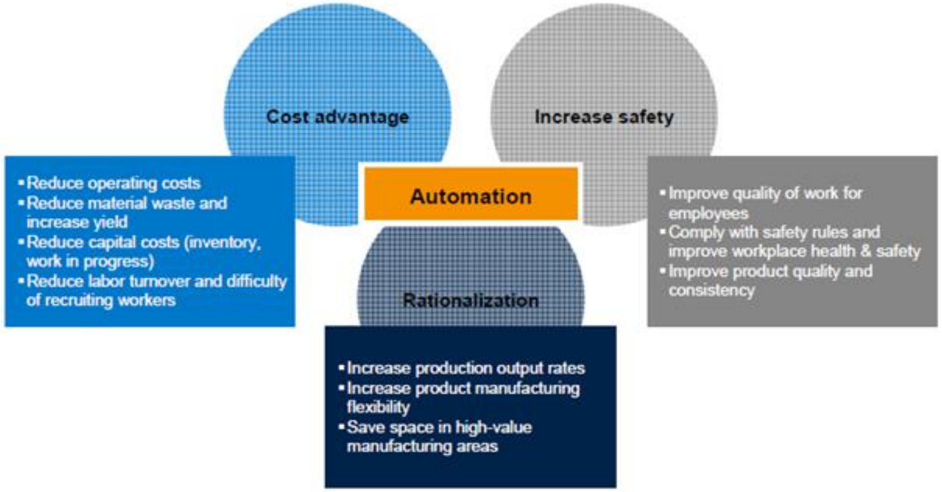
Pro' s and Con's automation

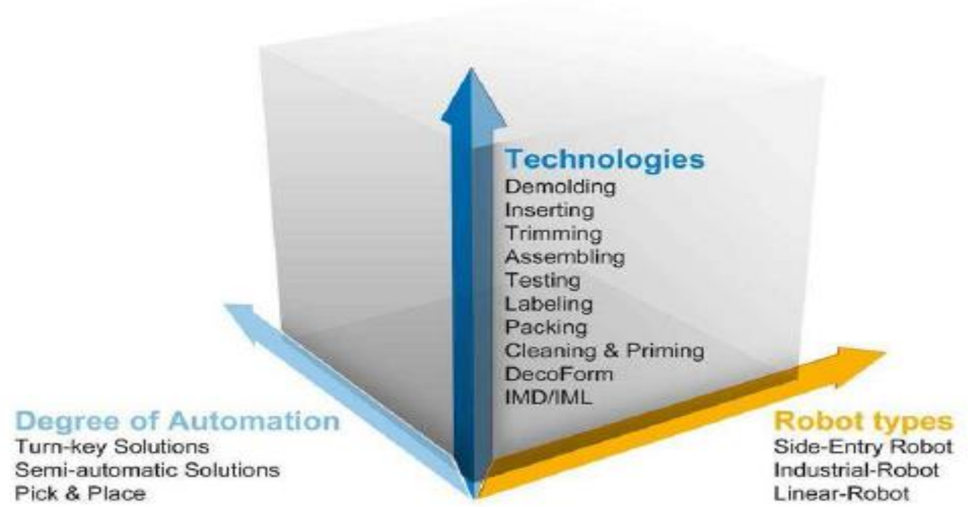
- + Robots work 24/7
- + High repeatability; high precision
- + 1st time right – every time
- + Robots can do dirty, tedious work
- + ROI within 0,5 - 2 year
- + More flexible to change processes than dedicated solution



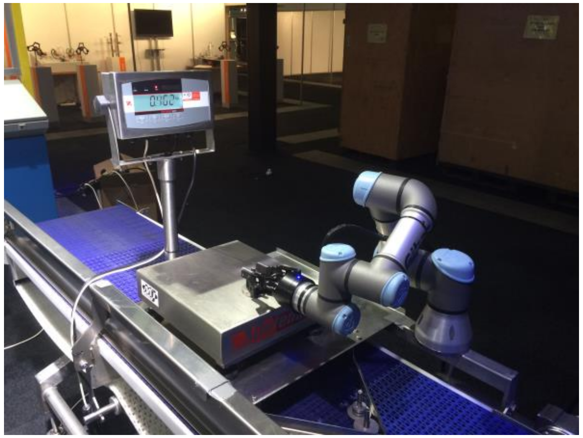
- Fixed cost; also at low utilization
- Not intuitive/ programmed response (is coming, fill force sensors, freedrive, 3D camera's)

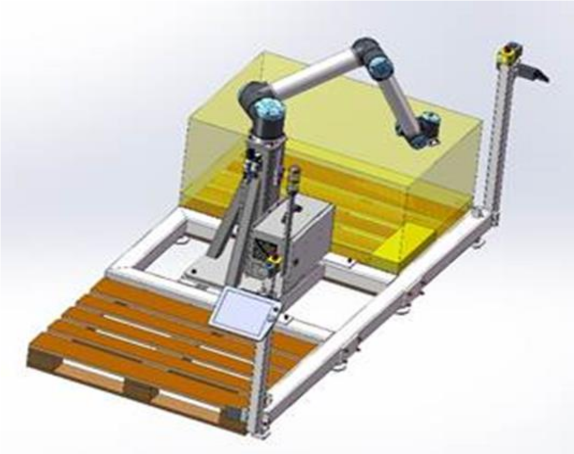
Group's view on automation

- For HCC and LCC's
- Start simple; learn by doing
- For demolding/ gluing/ welding/ assembly/ handling/ packing/ packaging/ mould cleaning
- Buy what is available; basic/ no LoR



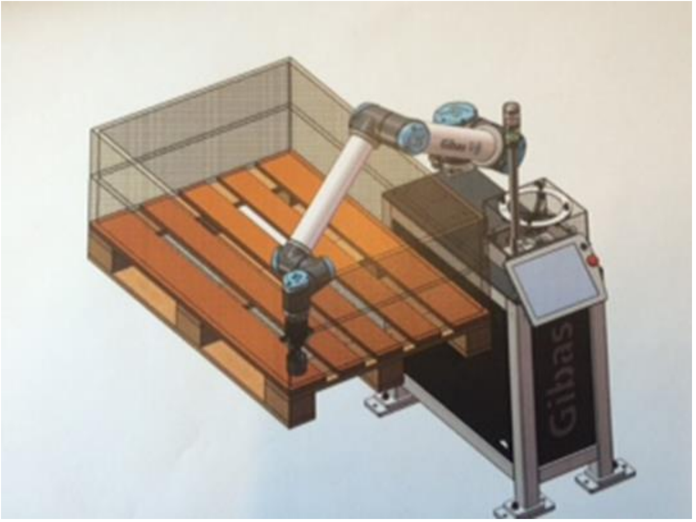
Loading weigh unit, place inserts in moulds, loading paper for placing tickets

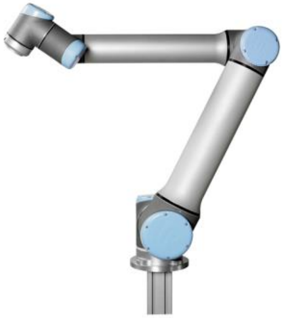




Introducing *Cobot* (cooperative robot) – UR10

- Reference: loading an Europallet with 2 side bars
- Repeatability ± 0,1 mm
- Robot weight < 30 kg
- Wrist weight max 10 kg
- 6-axial; radius 1.300 mm; 720°
- 22 inputs/ 20 outputs
- < 300 watt/ hour
- Simple maintenance
- 15 safety functions
- TŮV certified
- Mobile solutions possible





Example

- https://www.youtube.com/watch?v=CEWNyLeMGuU

Where Next for Digital Supply Chains?

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Where Next for Digital Supply Chains?

- 3D-printing located in our main wholesaler depots?
- https://www.youtube.com/watch?v=egFwvdlZWHk

Thank you

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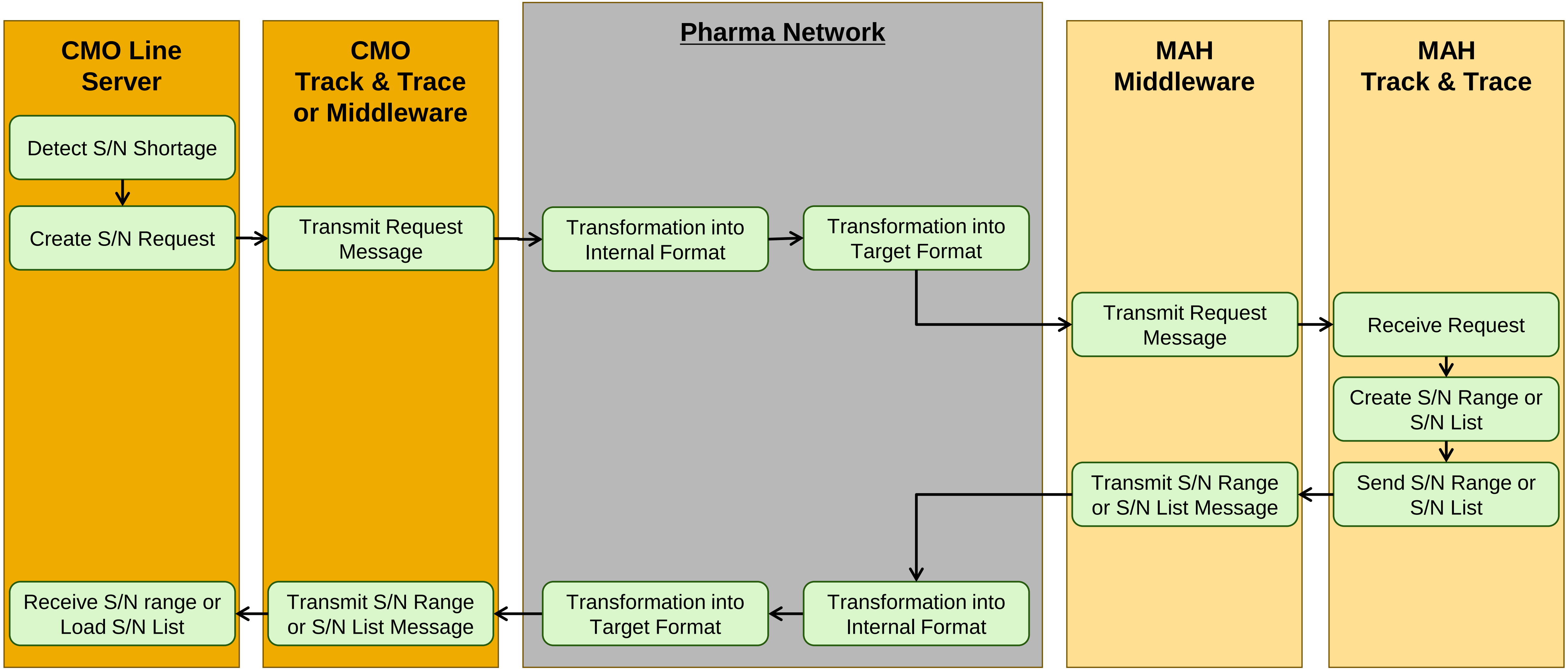
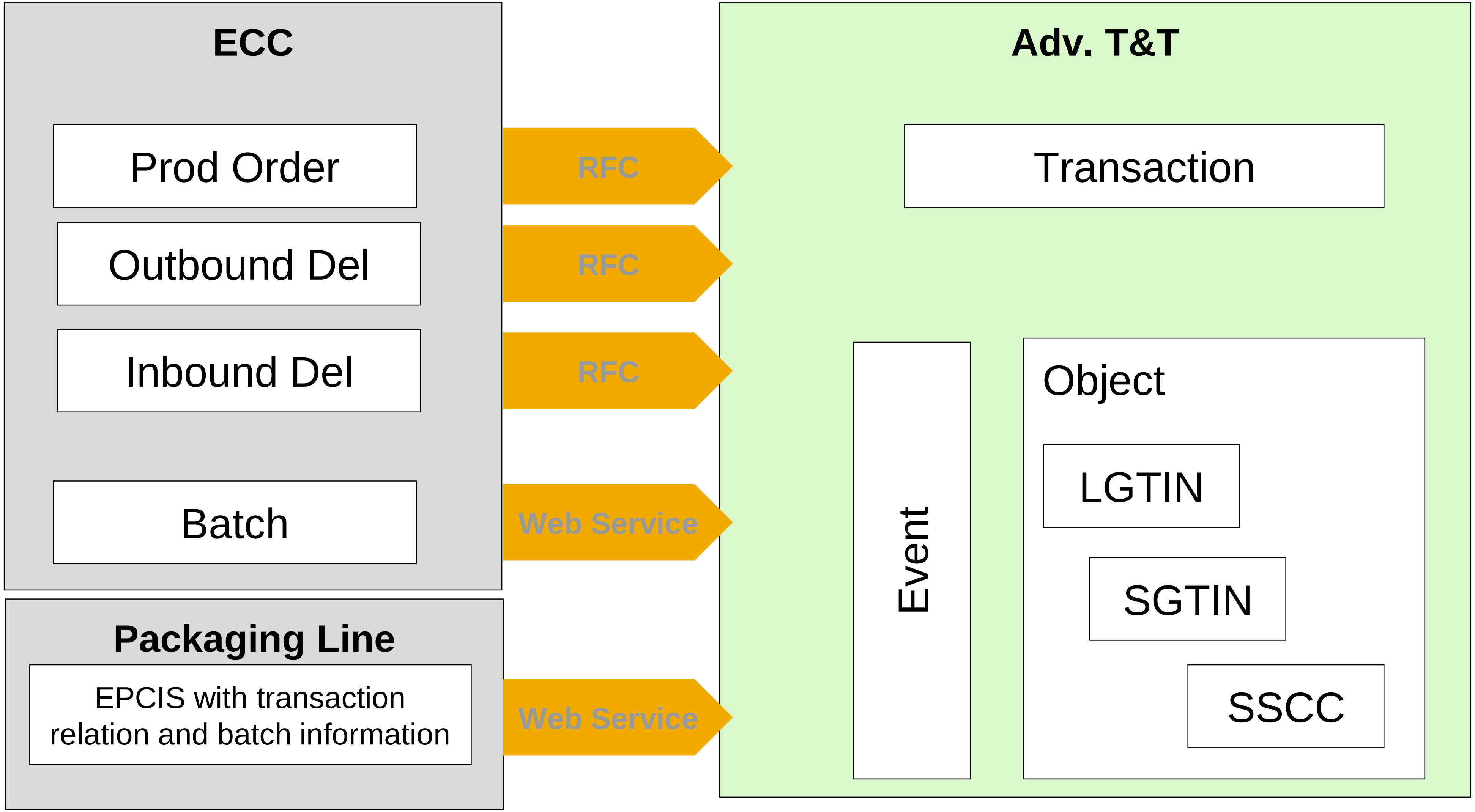
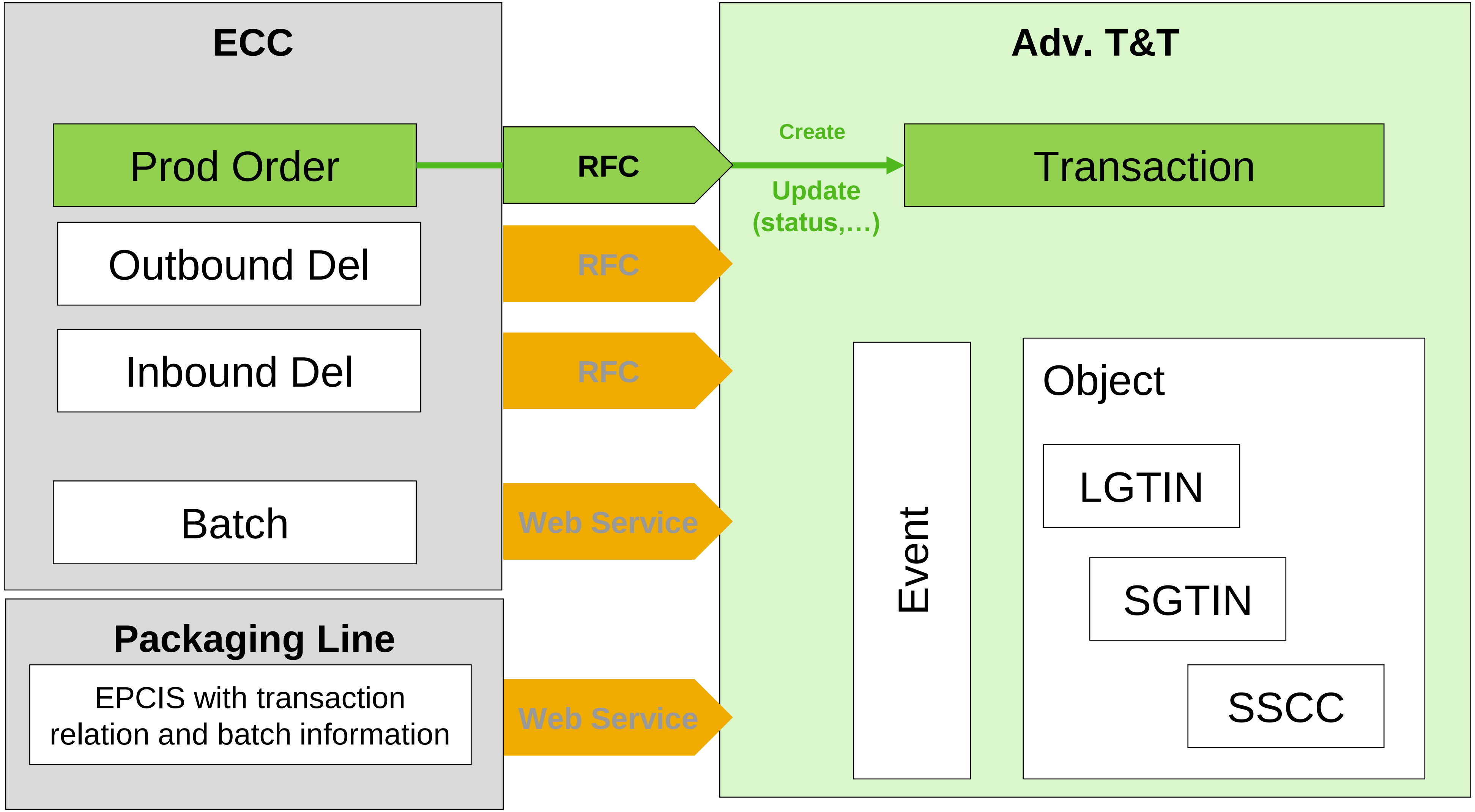
CMO S/N Request (machine-to-machine)



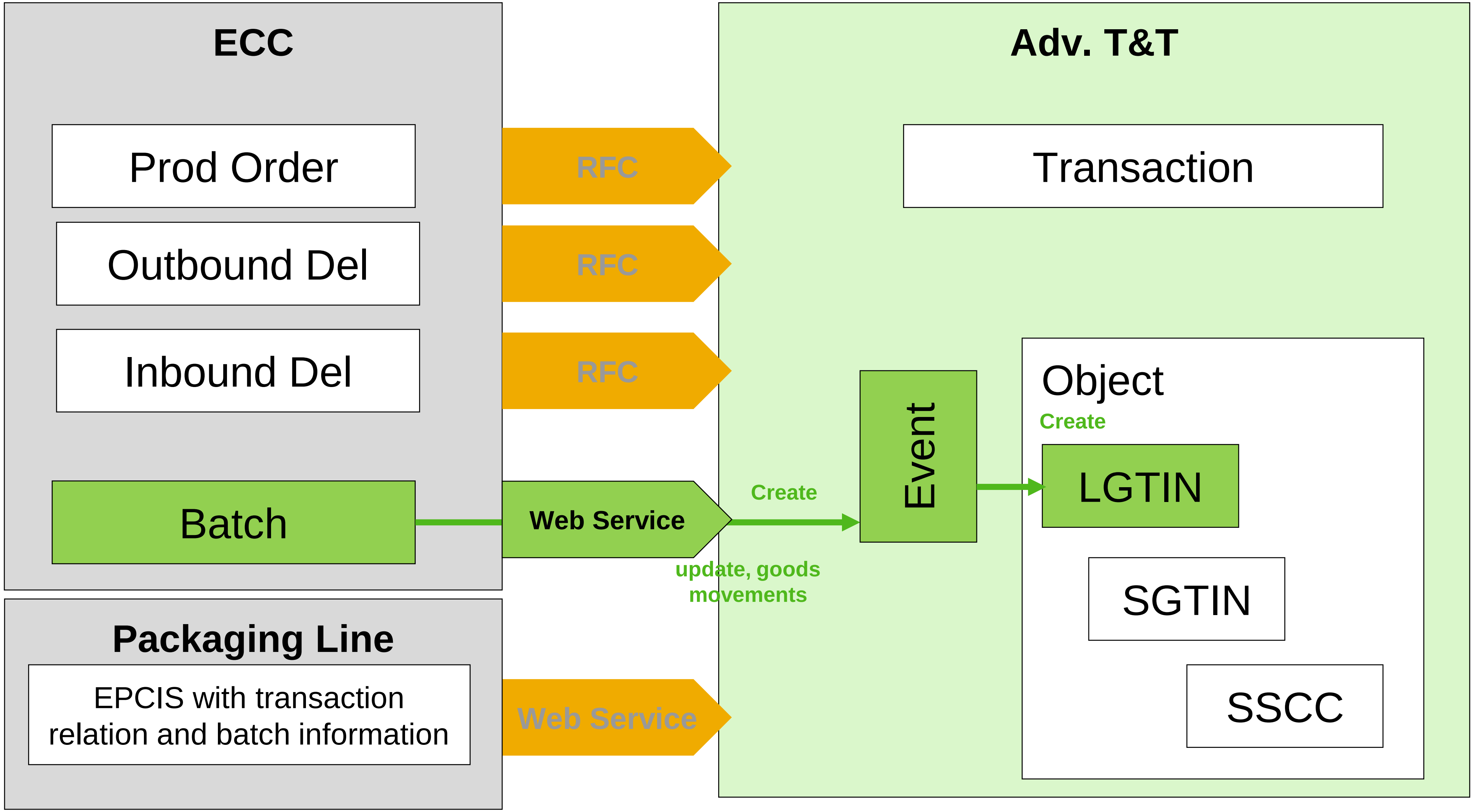
Transactional data and batch integration (simplified view)



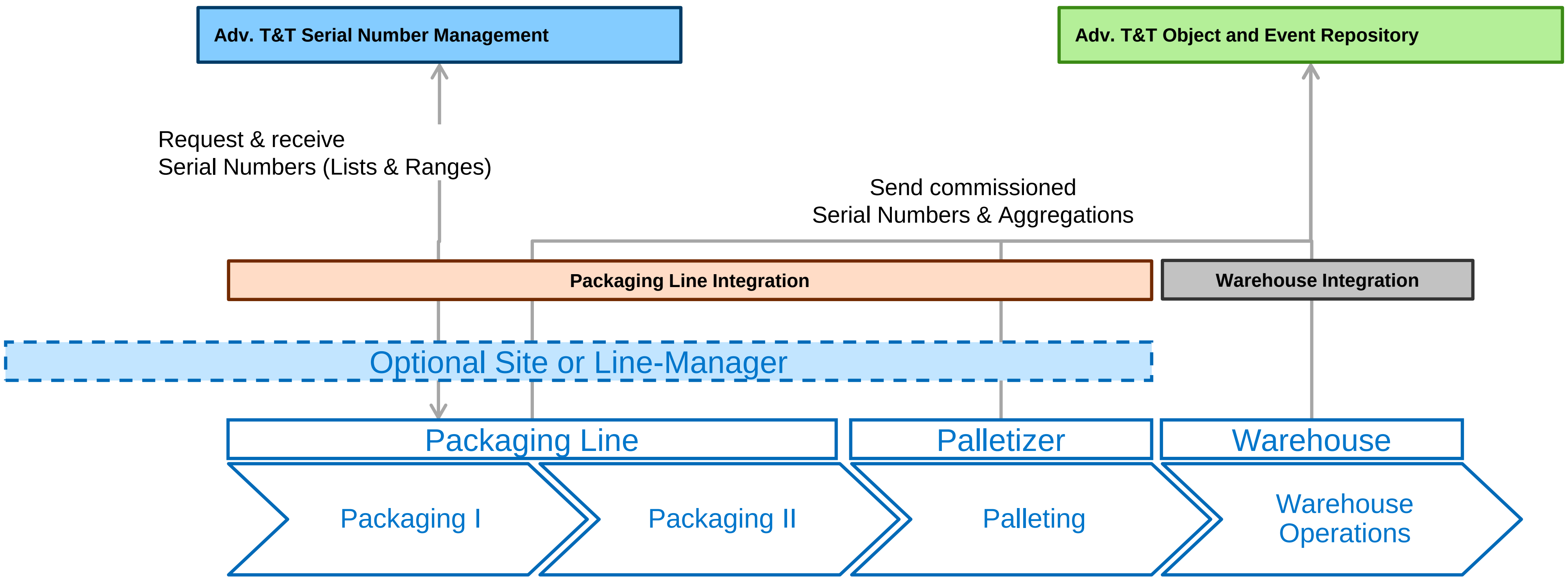
Transactional data and batch integration (Inbound Delivery - Create)



Transactional data and batch integration (Batch Creation)



Process Overview
Packaging and Warehouse Operations



Packaging I
- Primary packaging (e.g. tablets in blister)
- Secondary packaging (e.g. blister in folding box)
- Apply Barcode to secondary packaging
- Scan and Verify Barcode (Commissioning)

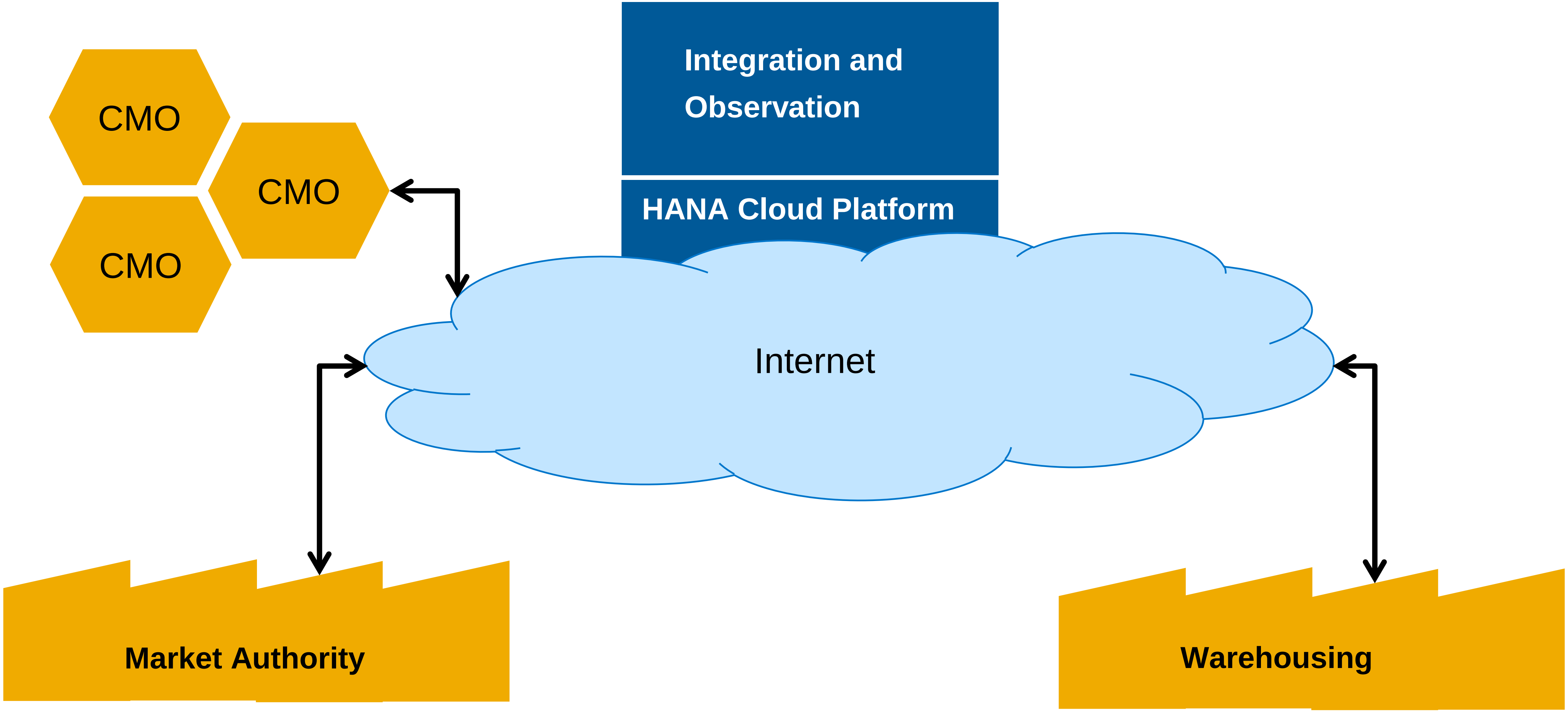
Packaging II
- Bundling (=Aggregation)
- Cartoning: Pack Bundles into Shippers (= Aggregation)

Palleting
- Palleting (=Aggregation)

Warehouse Operations
- Storage
- Pick/unpack (=De-aggregation)
- Pack (=Aggregation)
- Ship

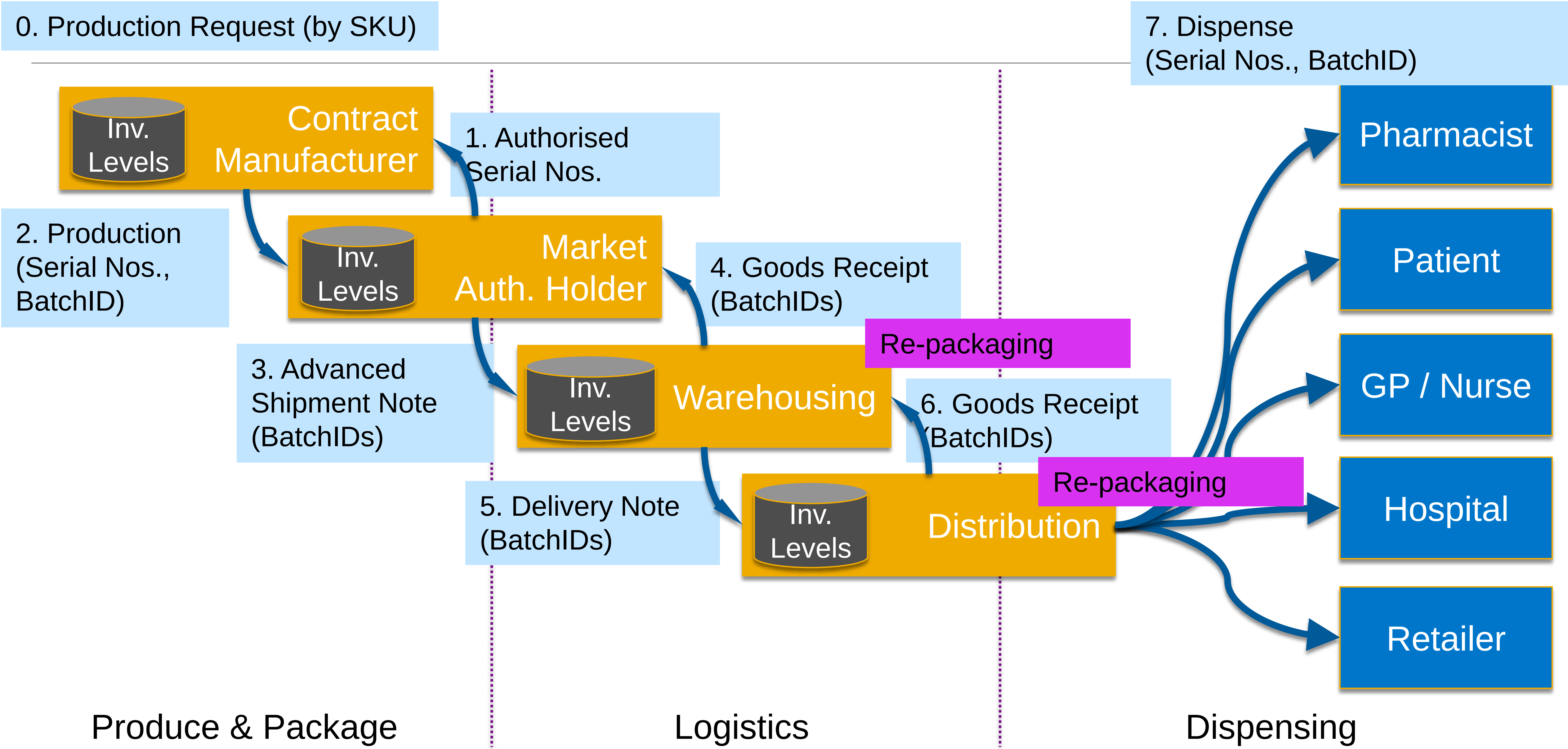
Cloud Enabled Solution

Cloud architecture enables this, through its neutral position

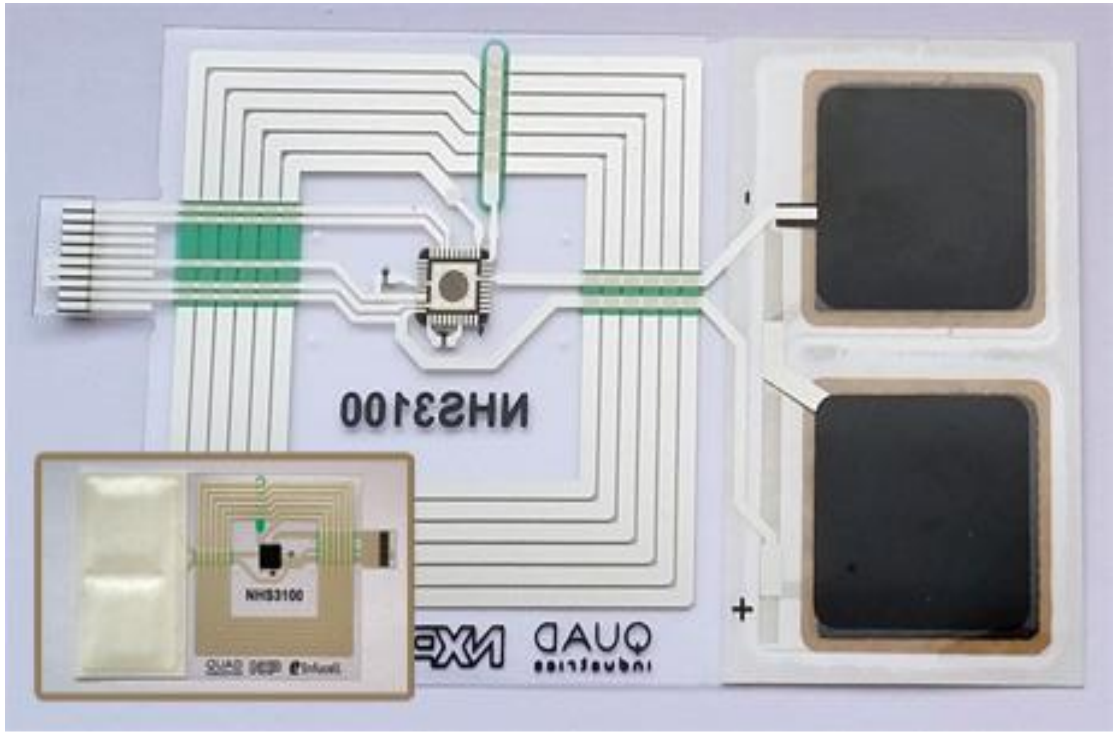


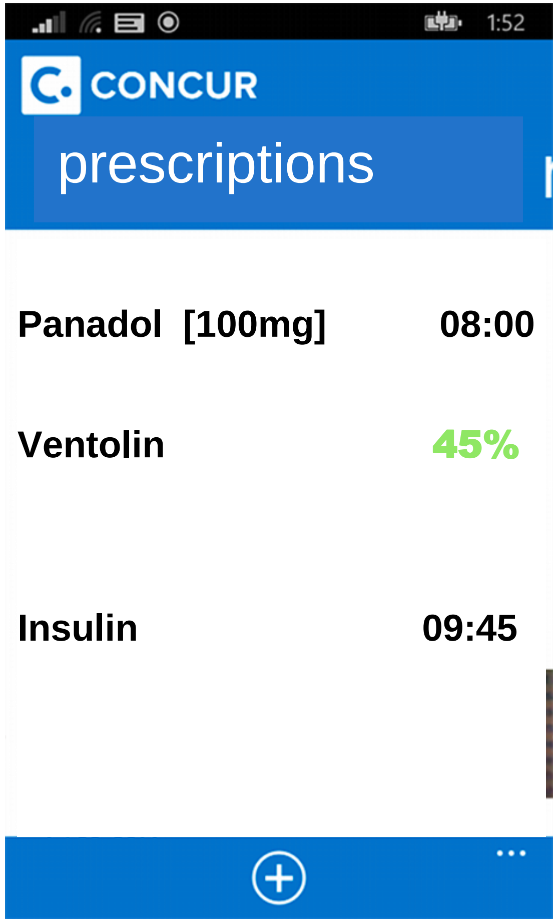
Possible Future Work

Simplified Supply Chain Data Sources



Complement with other data sources – Things and Apps…





DIGITALIZING THE MANUFACTURING ENTERPRISE OF THE FUTURE: INSIGHTS FROM 20 YEARS OF TECHNOLOGY RESEARCH

Ken Boyer

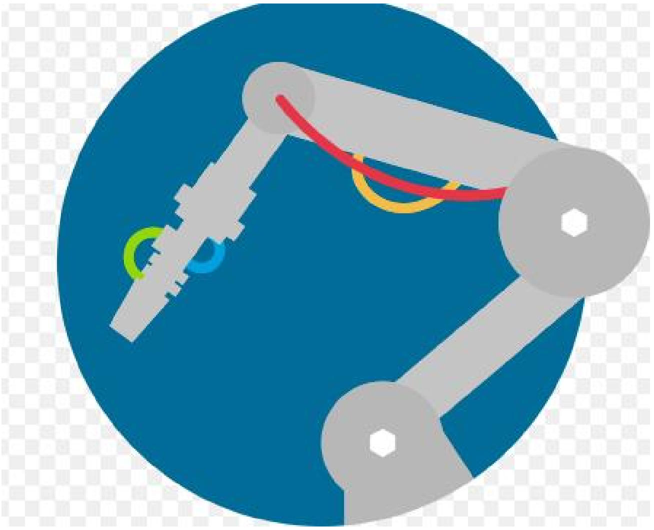
Fisher College of Business Professor of Operations Management

Chair, Management Sciences Department

Architecting the digital supply chain – the implications of digitalisation for global manufacturing – Cambridge Manufacturing Symposium 2016

The Ohio State University
Fisher College of Business

"Researchers have portrayed the factory of the future as based on AMTs and the economies of scope they engender: paperless, almost workerless and possessing the ability to produce a large variety of products cost effectively in lot sizes as small as one"



Boyer, K.K., Ward, P.T., Leong, G.K., (1996), Approaches to the Factory of the Future: An Empirical Taxonomy, *Journal of Operations Management*

WHERE WE WERE… 1994. RELATIVE TECHNOLOGY INVESTMENT

Table 3
Ranking of investments in advanced manufacturing technologies

Scale	Technology	Mean	Std. dev.
DESIGN (inter-item reliability (α) = 0.69, inter-rater reliability = 0.77)	Computer-aided design (CAD)	5.16	1.73
	Computer-aided engineering (CAE)	3.46	1.85
	Computer-aided process planning (CAPP)	3.04	1.84
Scale		3.93	1.45
MANUFACTURING (inter-item reliability (α) = 0.74, inter-rater reliability = 0.90)	Computerized numerical control (CNC)	4.78	2.01
	Computer-aided manufacturing (CAM)	4.04	1.94
	Environmental control systems	3.56	1.72
	Bar coding/automatic identification	2.94	1.91
	Real-time process control systems	2.76	1.80
	Flexible manufacturing systems (FMS)	2.45	1.71
	Automated material handling systems	2.34	1.58
	Group technology (GT)	2.26	1.68
	Robotics	2.06	1.57
Scale		3.05	1.03
ADMINISTRATIVE (inter-item reliability (α) = 0.79, inter-rater reliability = 0.80)	Material requirements planning (MRP)	4.10	1.96
	Office automation	3.93	1.58
	Manufacturing resource planning (MRP II)	3.92	2.01
	Activity-based accounting systems	3.39	1.87
	Electronic mail	3.26	1.95
	Electronic data interchange (EDI)	3.10	1.86
	Decision support systems	2.55	1.51
	Knowledge-based systems	2.12	1.37
Scale		3.34	1.16

Boyer, K.K., Ward, P.T., Leong, G.K., (1996), Approaches to the Factory of the Future: An Empirical Taxonomy, *Journal of Operations Management*

WHERE WE WERE …… 1994 ….. STRATEGIES FOR INVESTMENT

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Table 4
AMT dimensions by technology group

Measure	Advanced manufacturing technology group			
	TRADITIONALISTS, $n = 92$	DESIGNERS, $n = 25$	GENERALISTS, $n = 64$	HIGH INVESTORS, $n = 21$

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Boyer, K.K., Ward, P.T., Leong, G.K., (1996), Approaches to the Factory of the Future: An Empirical Taxonomy, *Journal of Operations Management*

WHERE WE WERE …… 1994 ….. PERFORMANCE

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Table 6
Plant size, integration and performance by AMT group

Measure	Advanced manufacturing technology group				
	TRADITIONALISTS, $n = 92$	DESIGNERS, $n = 25$	GENERALISTS, $n = 64$	HIGH INVESTORS, $n = 21$	
No. employees	(4)			(1)	
Cluster mean	328.25	305.46	722.73	1213.57	$F = 3.98$
Standard error	468.01	353.06	1353.70	2667.88	$p < 0.001$
Integration	(3,4)	(3,4)	(1,2,4)	(1,2,3)	
Cluster mean	2.42	2.62	3.58	4.47	$F = 23.61$
Standard error	1.07	1.14	1.21	1.55	$p < 0.001$
Sales growth					$n = 189$
Cluster mean	5.06	4.79	5.12	5.15	$F = 0.45$
Standard error	1.14	1.18	1.37	1.39	$p = 0.72$
Return on sales					$n = 167$
Cluster mean	4.79	4.18	4.92	5.11	$F = 2.39$
Standard error	1.45	0.96	1.12	0.96	$p = 0.071$
Earnings growth					$n = 166$
Cluster mean	4.75	4.23	4.96	4.94	$F = 1.97$
Standard error	1.29	1.18	1.08	1.26	$p = 0.12$

Note: Numbers in parentheses indicate the group numbers from which this group was significantly different at the $p < 0.05$ level according to the Scheffe pairwise comparison procedure. F statistics and associated p-values are derived from one-way ANOVAs.

Boyer, K.K., Ward, P.T., Leong, G.K., (1996), Approaches to the Factory of the Future: An Empirical Taxonomy, *Journal of Operations Management*

"How do firms evolve through technological investments?"

- Incremental Model
- Discontinuous Model

HOW THEY EVOLVED ------ 1996

Table 1 Sample Profile

	SIC CODE	Population[A] Number[A]	%	1994 Sample[C] Number[B]	%	1996 Sample[E] Number[D]	%
Number of Plants	33 Primary Metal	6,661	5.5	11	5.4	6	5.4
	34 Fabricated Metal	36,092	29.8	52	25.7	30	26.8
	35 Machinery, Except Elect.	52,091	42.9	90	44.6	48	42.9
	36 Electric & Electronic Eqpt.	15,922	13.1	9	4.5	4	3.6
	37 Transportation Eqpt.	10,505	8.7	40	19.8	24	21.4
	Total	121,271	100.0	202	100.0	112	100.0
Employees per Plant	Mean			413.5[F]		480.6	
Annual Sales	Mean (millions)			86.63[F]		92.83	

Notes:
A Source: United States Census of Manufactures (1987).
B Number of usable surveys, 1994 sample.
C 491 plants contacted, 1994 sample.
D Number of usable surveys, 1996 sample.
E 202 plants contacted, 1996 sample.
F Calculated for 112 plants which also participated in 1994 survey.

Boyer, K.K. "Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

HOW THEY EVOLVED ------ 1996

Table 3 Ranking of Investments in Advanced Manufacturing Technologies

Scale	Technology	1996 Mean	1994 Mean	Difference
	Computer-Aided Design (CAD)	5.17	5.04	0.13
DESIGN	Computer-Aided Engineering (CAE)	3.74	3.42	0.32*
	Computer-Aided Process Planning (CAPP)	3.12	2.79	0.33*
	Computerized Numerical Control (CNC)	4.80	4.71	0.09
	Computer Aided Manufacturing (CAM)	3.88	3.84	0.04
	Environmental Control systems	3.56	3.46	0.10
	Bar Coding/Automatic Identification	3.07	2.95	0.12
MANUFACTURING	Flexible Manufacturing Systems (FMS)	2.77	2.46	0.31**
	Real-time process control systems	2.75	2.68	0.07
	Automated material handling systems	2.32	2.19	0.13
	Group Technology (GT)	2.21	2.34	−0.13
	Robotics	2.15	1.96	0.19*
	Material Requirements Planning (MRP)	4.04	3.96	0.08
	Office automation	3.84	3.97	−0.13
	Electronic Mail	3.83	3.28	0.55***
ADMINISTRATIVE	Manufacturing Resource Planning (MRP II)	3.81	3.90	−0.09
	Electronic Data Interchange (EDI)	3.26	3.09	0.17
	Activity-based accounting systems	3.11	3.31	−0.20
	Decision support systems	2.49	2.59	−0.10
	Knowledge-based systems	2.24	2.04	0.20

Notes: 1. Each technology shows the mean of all respondents' answers on a seven point scale asking them to rate the amount of investment in each technology between the extremes of 1 = no investment and 7 = heavy investment.
2. A paired sample t-test is used to calculate significance values for differences. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Boyer, K.K. "Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

HOW THEY EVOLVED ------ 1996

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Incremental

All-in

Table 5 1996 Advanced Manufacturing Technology Groups

Measure	1 TRADITIONALISTS [n = 35]	2 DESIGNERS [n = 28]	3 GENERALISTS [n = 37]	4 HIGH INVESTORS [n = 12]	
DESIGN96	(2,3,4)	(1,4)	(1,4)	(1,2,3)	
Cluster Mean	2.63	4.68	4.23	6.06	F = 75.4
Standard Deviation	0.77	0.81	0.72	0.74	$p < 0.001$
MANUFACTURING96	(3,4)	(3,4)	(1,2,4)	(1,2,3)	
Cluster Mean	2.40	2.46	3.69	4.55	F = 44.3
Standard Deviation	0.73	0.73	0.66	0.80	$p < 0.001$
ADMINISTRATIVE96	(3,4)	(3,4)	(1,2,4)	(1,2,3)	
Cluster Mean	2.59	2.75	4.05	5.03	F = 54.5
Standard Deviation	0.76	0.72	0.63	0.68	$p < 0.001$

Note: Numbers in parentheses indicate the group numbers from which this group was significantly different at the $p < 0.05$ level according to the Scheffe pairwise comparison procedure. F statistics and associated p-values are derived from one-way ANOVAs using the 1996 data.

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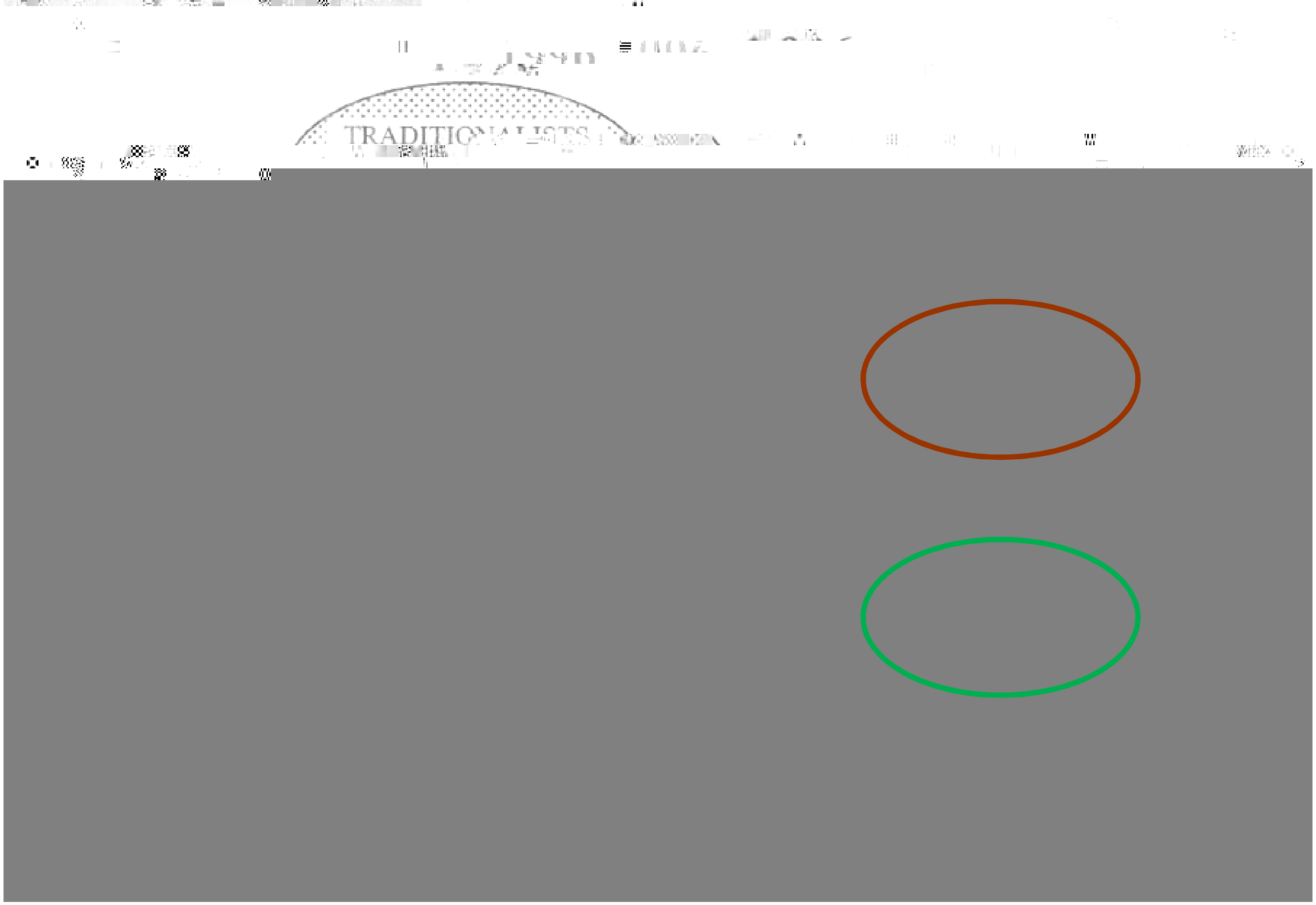
Boyer, K.K. "Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

WHAT ROLE DID LEADERSHIP PLAY?

Figure 2 Manufacturing Involvement and AMT Investment



Boyer, K.K. "Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

PERFORMANCE RESULTS

Table 7 1994 Performance by 1994 Technology Group

Performance Measure	1 TRADITIONALISTS [n = 59]	2 DESIGNERS [n = 12]	3 GENERALISTS [n = 29]	4 HIGH INVESTORS [n = 12]	
	1994 Advanced Manufacturing Technology Group				
PROFIT (1994)					
Cluster Mean	4.71	4.14	4.92	4.89	$F = 1.30$
Standard Error	1.35	1.01	0.85	1.27	$p = 0.28$
GROWTH (1994)					
Cluster Mean	4.98	4.58	5.48	4.88	$F = 2.02$
Standard Error	1.11	1.24	1.06	1.04	$p = 0.12$

Performance Measure	1 TRADITIONALISTS [n = 59]	2 DESIGNERS [n = 12]	3 GENERALISTS [n = 29]	4 HIGH INVESTORS [n = 12]	
	1994 Advanced Manufacturing Technology Group				
PROFIT (1996)	(3)	(3)	(1,2)		
Cluster Mean	4.40	3.60	5.31	4.74	$F = 4.88$
Standard Error	1.39	1.49	1.05	1.39	$p < 0.01$
GROWTH (1996)					
Cluster Mean	4.50	4.33	5.22	4.80	$F = 2.31$
Standard Error	1.35	1.23	1.06	1.44	$p = 0.08$

Note: Technology groups are based on 1994 data, while performance is from 1994 data (top half of table) and 1996 (bottom half of table). Numbers in parentheses indicate the group numbers from which this group was significantly different at the $p < 0.05$ level according to the Scheffe pairwise comparison procedure. F statistics and associated p-values are derived from one-way ANOVAs.

Boyer, K.K. **"**Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

PERFORMANCE RESULTS

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Table 8 **Objective Performance Measures**

Objective Performance Measure	Low AMT Investment	*n*	High AMT Investment	*n*	*F*	*p*
Sales Growth	9.16%	57	16.27%	34	4.80	0.03
Manufacturing Costs	58.49%	44	57.23%	27	0.06	0.81
Return on Sales	9.39%	33	12.04%	21	0.92	0.34
Earnings Growth	5.95%	33	18.03%	20	0.96	0.33
Market Share	34.00%	45	38.44%	25	0.46	0.50

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Boyer, K.K. "Evolutionary Patterns of Flexible Automation and Performance: A Longitudinal Study", *Management Science*, Vol. 45, No. 6, 1999, pp. 824-842.

Lesssons/Findings

- Technical Leadership Matters
- Benefits are not immediate
- Workforce Enhancement is critical
- Some Evidence that Discontinuous or “All In” investment is best

From Online Retailing (2002) to Omni-Channel Commerce (2016)

MOTIVATION

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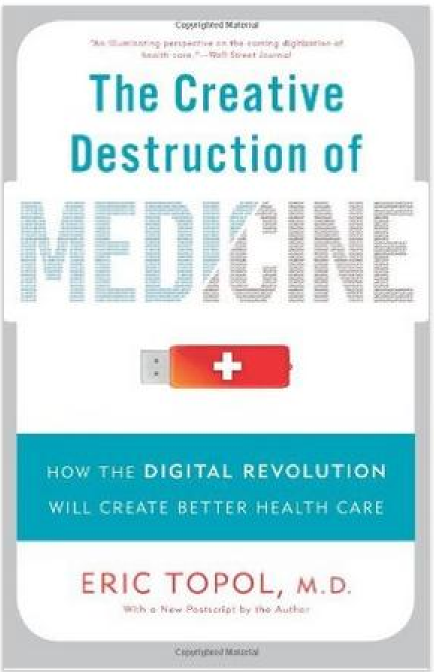
Healthcare IT News

Study: Health IT spending to top $34.5B

Well-positioned vendors could secure lion's share

HAMPTON, N.H. | August 29, 2013



THE WALL STREET JOURNAL.

Home World U.S. Politics Economy Business Tech Markets Opinion Arts Life Real Estate

REVIEW & OUTLOOK The Clintons and the Emirates

REVIEW & OUTLOOK Home Front Hero

REVIEW & OUTLOOK Missile Defense for Korea

A Path Out of the Middle East Collapse

ObamaCare's Electronic-Records Debacle

The rule raises health-care costs even as it means doctors see fewer patients while providing worse care.

THE WALL STREET JOURNAL. U.S.

9:03 am ET
Sep 28, 2015 HEALTH

How Electronic Medical Records Distract Nurses—and Harm Patients

Sharma, L., Chandrasekaran, A, Boyer, K.K, McDermott, C., 2016, "The Impact of Health Information Technology Bundles on Hospital Performance", Journal of Operations Management.

Literature Gap

Positive	Neutral	Negative
Devaraj & Kohli. (2000; 2003)	Linder et al., 2007	Ash, Berg, & Coiera, 2004
Queenan, Angst & Devaraj (2011)	DesRoches et al. 2010;	Han et al. 2005
Angst, Devaraj & D'Arcy (2012)	McCullough, Casey, Moscovice, & Prasad, 2010	Koppel et al. 2005

Reasons for Mixed results in Literature

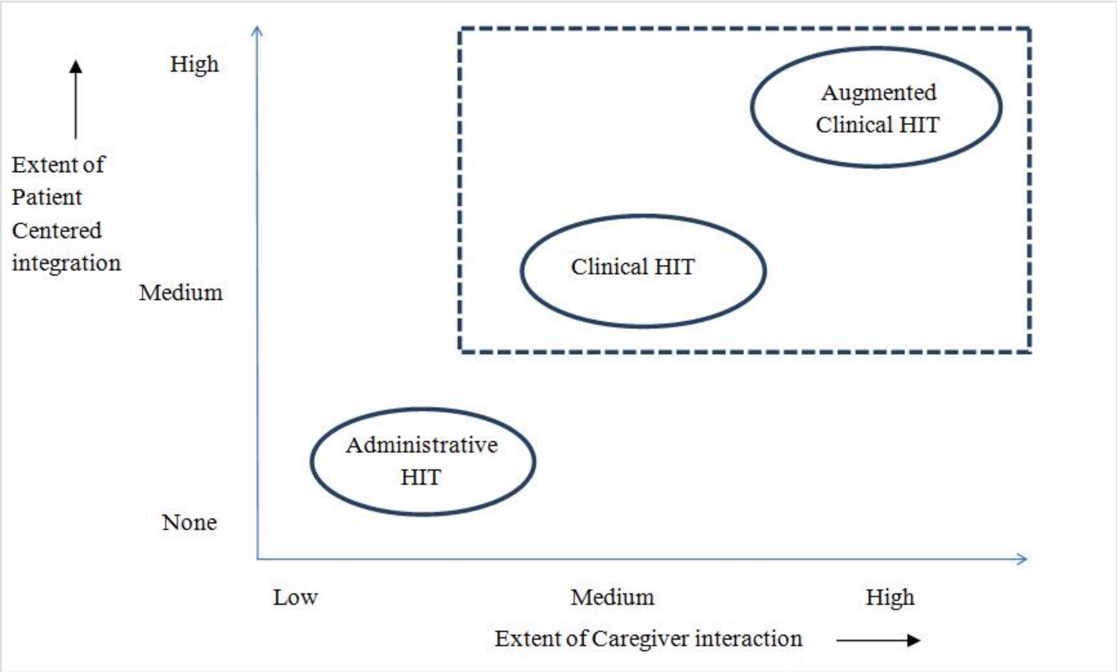
- Focus on a small number of technologies
- Focus on specific hospital settings
- Single performance dimension
- Focus on final quality of care measures such as mortality and readmissions.
- Use of Cross Sectional data

APPROACH USED

- Insights from AMT research suggests that benefits of technology accrued as the result of two factors:
  - Integration of multiple technologies
  - Recognition of the critical importance of human capital (i.e. the interaction between users and systems)

- Based on the AMT literature and Gaps in current studies our approach involves:
  - Examining HIT as an amalgamation of multiple technologies.
  - Recognizing the degree of interface between HIT and different types users (e.g. physicians, nurses, technicians).
  - Use of a large longitudinal data set of 3615 US hospitals from the 2007-2012

HIT CLASSIFICATION



	Administrative HIT	Clinical HIT	Augmented Clinical HIT
Core Functions	Administrative support and data integration.	Patient data collection, diagnosis and treatment	Patient data integration, reporting and decision support.
Typical Users	Administrative Staff	Technicians, Nurses and Physicians	Nurses and Physicians
Major Emphasis on Adoption	Pre HITECH Act. Continued emphasis since the 1980s	Continued emphasis since the 1990s	Continued emphasis post the HITECH Act.

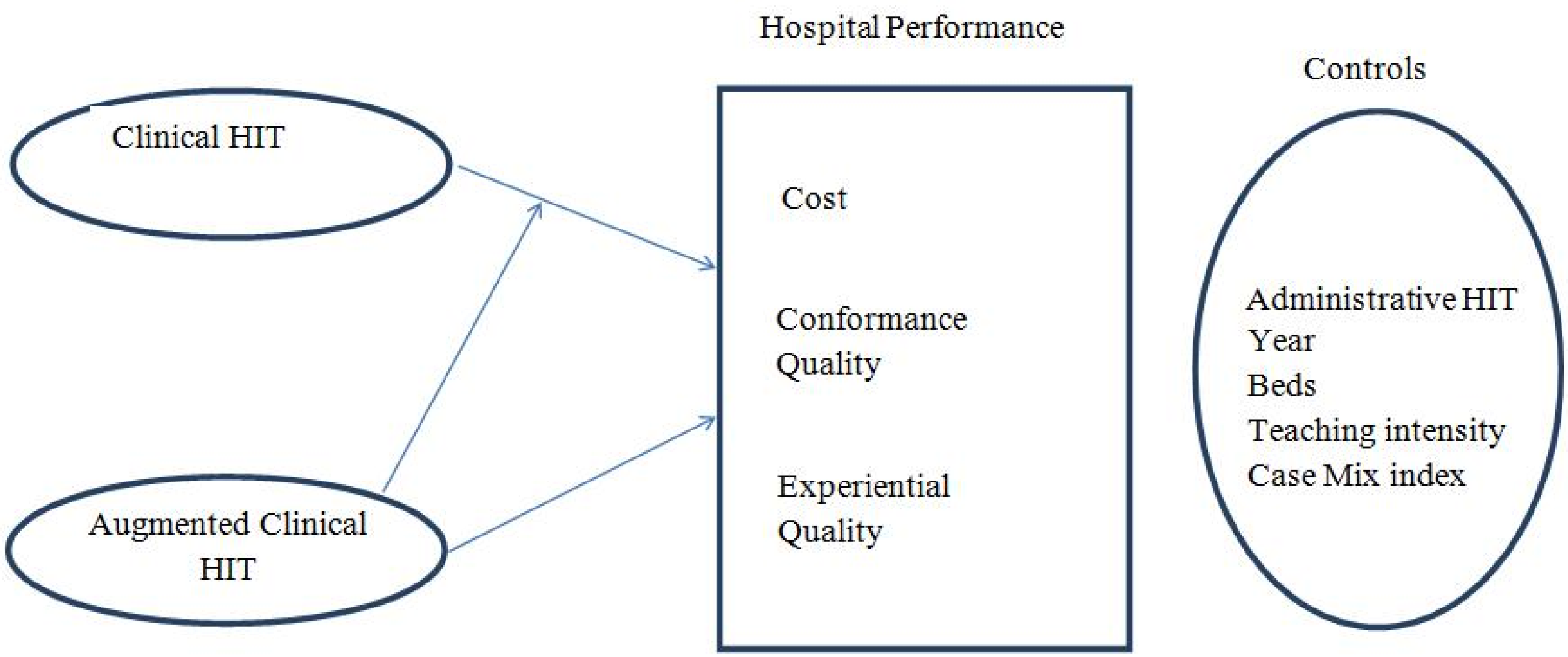
- HIMSS tracks maturity of EMR adoption through its EMR adoption model.
- EMR adoption model is used as a basis to determine
  - EMR HITs

- EMRs consist of the following HITs:
  - Pharmacy Information System
  - Laboratory Information System
  - Radiology Information System
  - Clinical Data Repository (CDR)
  - Nursing Documentation
  - Electronic medical administration records (EMAR)
  - Clinical decision support (CDS)
  - Computerized physician order entry (CPOE)

VARIABLES DESCRIPTION

- *Clinical HIT*: Deals with collection, testing and processing of patient data for medical purposes or in treating patients.
- *Augmented Clinical HIT*: Integrates several Clinical HIT systems and adds decision support and reporting capabilities to the data collected by clinical systems.
- *Administrative HIT*: Associated with financial and administrative information flows within a hospital.
- *Conformance Quality:* The degree of adherence to the Center of Medicare and Medicaid Services (CMS) process of care measures at a hospital.
- *Experiential Quality*: The quality of interactions between the caregivers and patients as perceived by the patient at a hospital.
- *Cost*: The operating costs incurred by a hospital per bed.

RESEARCH FRAMEWORK



DATA SOURCES AND METHODOLOGY

DATA SOURCES

- Data on 3650 US acute care hospitals from 2007-12
- Four secondary databases combined for this study
  - HIMSS Analytics database for HIT adoption process
  - CMS process of care for conformance quality
  - CMS HCAHPS for caregiver communication
  - CMS Cost reports for Operating cost

METHODS

- Q-Sort to group HITs into Clinical, Augmented Clinical and Administrative
- Instrument variable 2 stage least squares within effects estimator
  - Uses lagged values of endogenous variables as instruments.

RESULTS: MAIN ANALYSIS

	Cost	Conformance Quality	Experiential Quality
Clinical HIT	NS	+	+
Augmented Clinical HIT	NS	NS	NS
Clinical HIT * Augmented Clinical HIT	NS	+	+

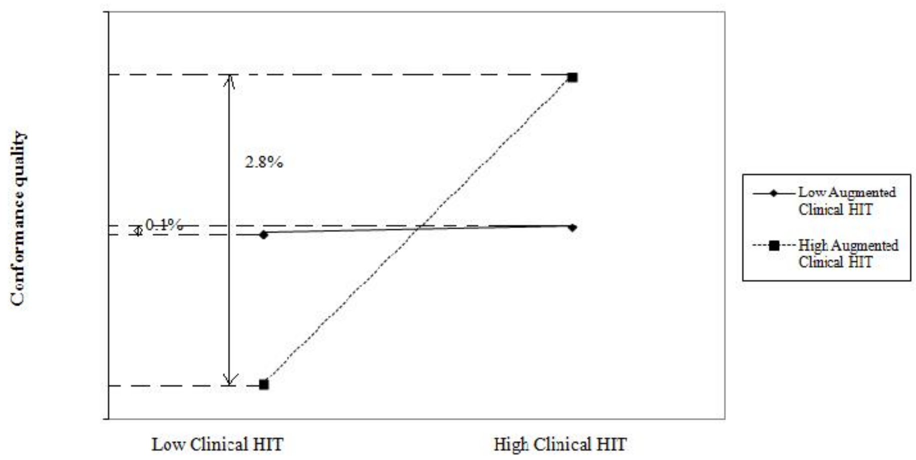
H1 Not Supported

H2 Supported

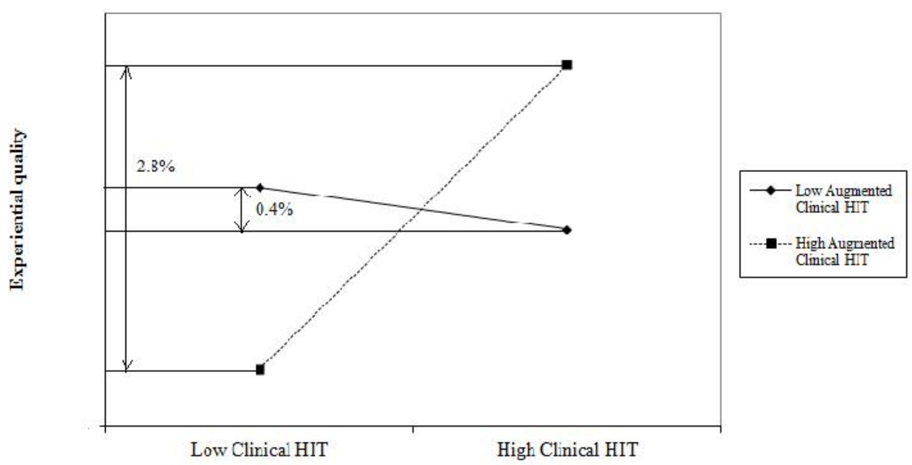
H3 Not Supported

INTERACTION PLOTS

Conformance Quality



Experiential Quality



Findings

- Complementarities between Clinical and Augmented Clinical HIT with respect to process of care outcomes but not with respect to cost outcomes
- EMR HITs have complementarities with Clinical HITs for conformance quality while negative synergies are observed for cost performance.
- Non-EMR HITs have complementarities with Clinical HITs for cost and experiential quality

“Takeways ……….

IT/Automation Initiatives for FoF?

AUTOMATION REQUIREMENTS

- Information as well as mechanical automation
- Product/order tracking
- Resilient to changes
- Support customisation
- Multiple locations
- Services as well as products

→ ?

IT/AUTOMATION INITIATIVES

- Auto ID / IoT
- [distributed] AI, Agents, cyber phys
- Big Data
- Intelligent Products
- Physical Internet

Auto ID Systems

What is the challenge?

Using RFID/QR/Bluetooth/RTLS to detect item level movements in industrial supply chains to answer operational T&T issues.

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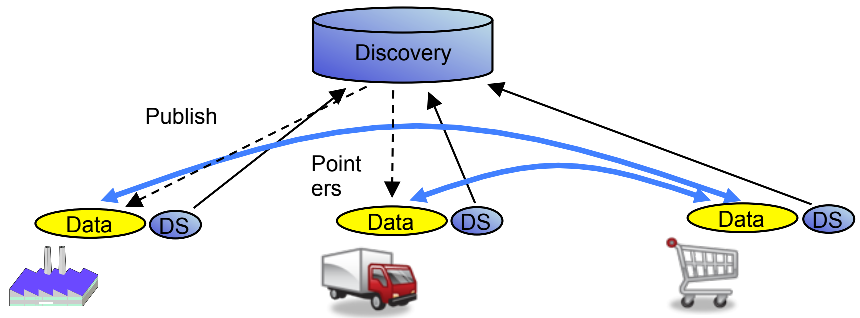


Outputs

- Accurate tracking across multiple locations
- Traceability / pedigree guarantees
- Physical Items on network

Benefits?

- Inventory & labour reduction
- Reduced lost time
- Improved operational decision making in production & logistics

Distributed & Automated Intelligence

What is the challenge?

Development of appropriate solutions for embedding intelligence into industrial products and resources to allow them to interaction & steer / influence their own operations

Outputs

- Adaptable control systems with limited fixed rules
- Inherent disruption resilience through reactive approach
- Ability to interact with / reason about changing order requirements

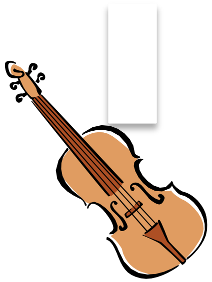
Intelligent Products & Orders

What is the challenge?

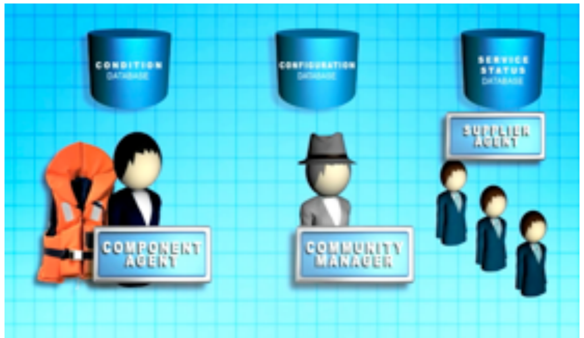
Enabling a physical order or product to <u>support or influence</u> the way it is made, stored or transported

Benefits?

- Support customer preferences in manufacturing & logistics
- Provide manufacturer or logistics provider with capability to manage high levels of customisation



Customised violin



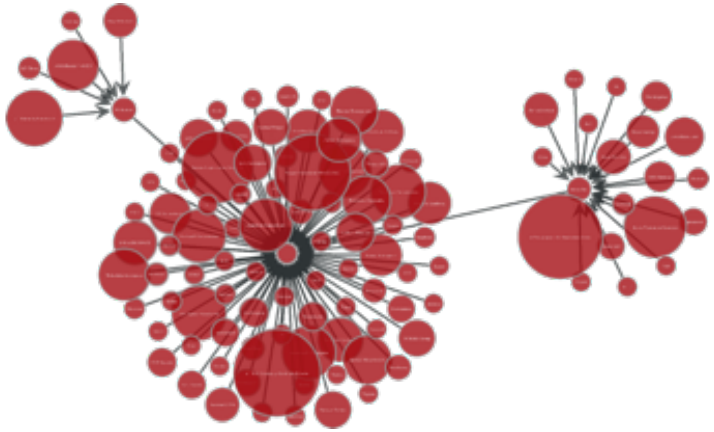
[Industrial] Big Data

What is the challenge?

Efficiently collecting, aggregating an analysing large data volumes originating from many different sources

Benefits?

- Reduced manual data management
- Access to new data sources
- Leverage data analytics tools
- Examine SC wide issues & beyond



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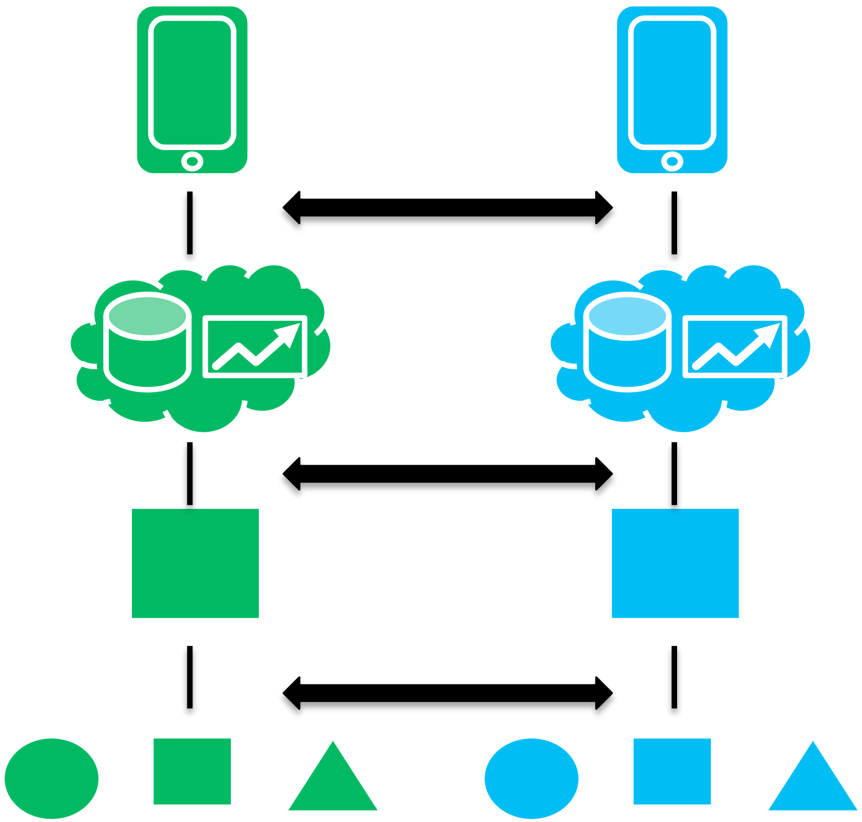
IfM

Industrial IoT – evolution not revolution



1. BASE: Monitoring condition and location of orders

2. INTEGRATED: Ability to check product integrity, order status, quality conditions

3. INTELLIGENT: Ability to allow for controlled customisation of orders, adaptation in the face of quality issues / delays

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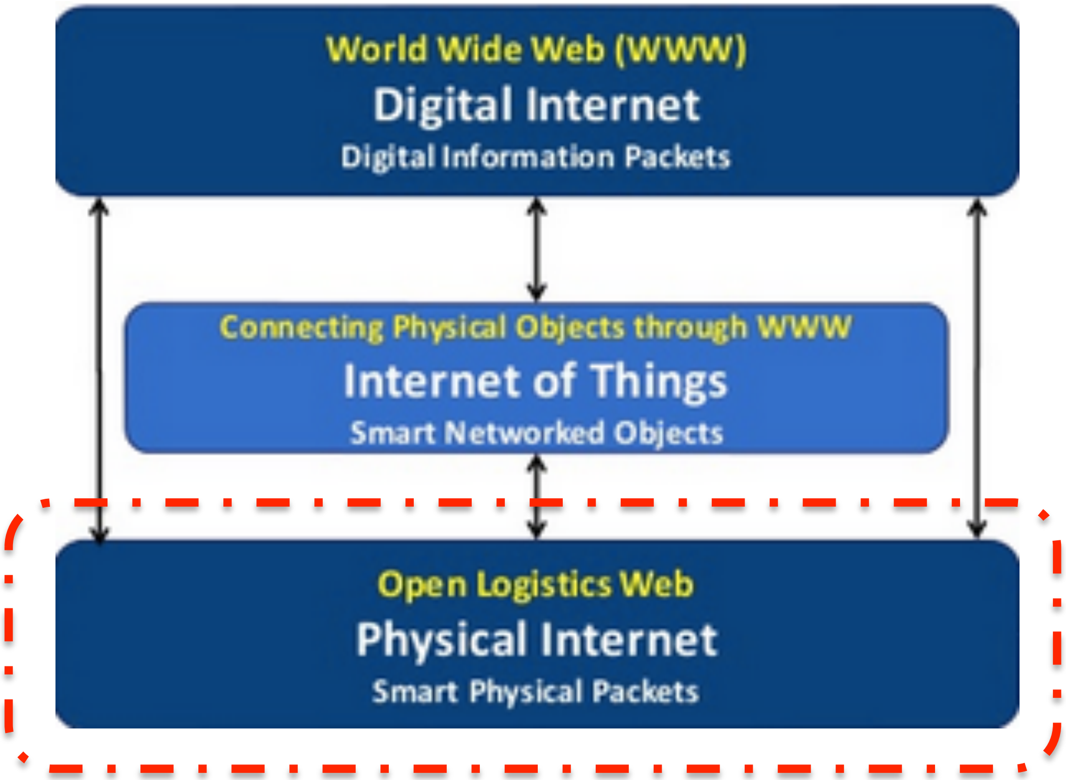
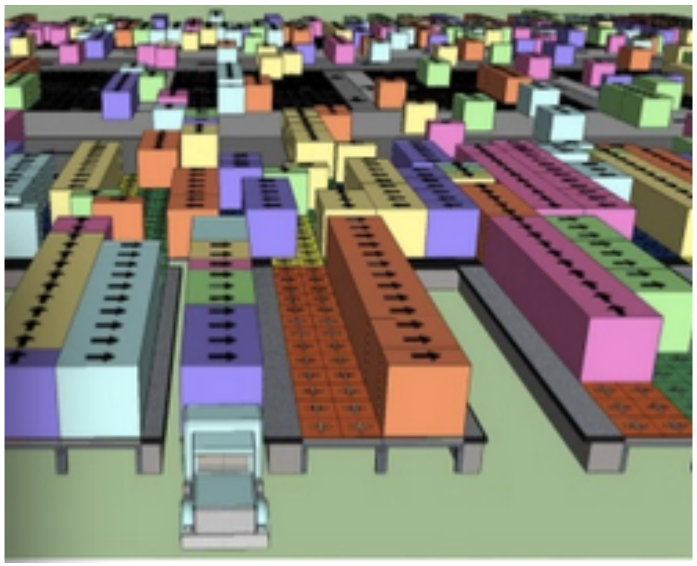
IfM

Physical Internet [for Goods Logistics]



Benefits:

- Modular Containers
- Packet based approach to transport
- Standardised nodes / routes for logistics
- Resilient to some disruptions



IT/Automation Initiatives for FoF?

AUTOMATION REQUIREMENTS → IT/AUTOMATION INITIATIVES

AUTOMATION REQUIREMENTS

- Information as well as mechanical automation
- Product/order tracking
- Resilient to changes
- Support customisation
- Multiple locations
- Services as well as products

IT/AUTOMATION INITIATIVES

- Auto ID / IoT
- [distributed] AI, Agents, cyber phys
- Big Data
- Intelligent Products
- Physical Internet

IT/Automation Initiatives for FoF?

FACTORIES OF THE FUTURE

requirements ↓ ↑ *addressing*

AUTOMATION CHALLENGES

requirements ↓ ↑ *addressing*

IT / AUTOMATION INITIATIVES

Situation awareness as a building block of purchasing and supply management capability

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Abstract

This conceptual paper reviews the situation awareness literature for PSM insights, and proposes a PSM relevant situation awareness model with implications to theory and practice. The review considers the concept of situation awareness, its applicability and relevance in various contexts, the challenges for achieving situation awareness, and the aspects of improving situation awareness. It is concluded that despite PSM differing from the usual contexts of application of the situation awareness concept, many of its potential characteristics make situation awareness a highly relevant perspective for purchasing professionals, as situation awareness enables PSM function to adapt to the environment, and to retain relevance and reach its strategic potential. By elaborating the three-level model of situation awareness (Endsley, 1995) from the PSM perspective, we focus attention on the individual as a decision maker and change agent in PSM. Further research on e.g. category cards, sourcing levers and future planning in PSM are proposed.

Key words: purchasing, supply management, situation awareness, capability, decisions

1. Introduction

Compelling theoretical argumentation has been presented in support of the contribution of purchasing and supply management (PSM) on the competitive advantage of the firm (e.g. Barney, 2012). These resource-based view (RBV; e.g. Wernerfel, 1984; Peteraf, 1993) -grounded perspectives focus on building and maintaining heterogeneous PSM capabilities, which should be valuable, rare, inimitable and not easily substitutable (Barney 1991). Indeed, whether PSM is strategic, and therefore with a similar level of impact, has been argued to be associated with the function’s ability to develop superior capabilities (van Weele and van Raaij, 2014). Building and developing such capabilities for ‘external resource management’ (van Weele and van Raaij, 2014) may be challenging, especially with the hypothesis that internally grown capabilities are more likely to meet the characteristics that contribute to sustainable competitive advantage (Barney, 2012).

The capability to form combinations of internal and external resources for capturing business opportunities, as well as finding and managing the best available external resources (Tanskanen et al., 2014) lies at the heart of external resource management. Indeed, “whether PSM is strategic depends on its ability … to develop and sustain superior codified knowledge of markets and supply chains” (van Weele and van Raaij, 2014, 68). However, the challenge in this strategic effort lies in the fact that comprehending the state of and detecting changes in the possibly dynamic and uncertain external resource pool requires a great deal of time and effort from the purchasing professionals, and thus cannot be taken for granted. Extant literature on for example absorptive capacity (Cohen and Levinthal, 1990), point out the significance of ‘firm’s capability to identify and acquire externally generated knowledge that is critical to its operations’, as well as ‘firm’s routines and processes that allow it to analyze, process, interpret, and understand the information obtained from external sources (Zahra and George, 2002), on innovative performance and competitive advantage of firms (e.g. Chen et al., 2009; Kostopoulos et al., 2011). While useful for understanding adaptation of companies in response to external knowledge, “the specific organizational routines and processes that constitute absorptive capacity capabilities remain a black box”, encouraging research on the microfoundations of this concept (Lewin et al., 2011, 81). Relatedly, the attention-based view of the firm (Ocasio, 1997), seeks to explain “how managerial attention is allocated for the identification and evaluation of potential opportunities” (Shepherd et al., 2016), whereas various cognitive theories have been suggested to explain entrepreneurs’ opportunity recognition and exploitation (Zahra et al., 2005). Despite these efforts, the practical building blocks for firm’s adaptation capability remain elusive.

In this paper, a novel approach is taken for understanding the routines that may serve as capability building blocks (Peng et al., 2008; Wu et al., 2010) for developing and sustaining superior knowledge of markets and supply chains in the PSM function, needed for adaptation and alignment. We draw on the body of literature and theories on “situation awareness”, prominent in the safety science in general, and the aviation industry in particular, which can be defined in general terms as “individual’s dynamic awareness of the ongoing external situation” (Salmon et al., 2008, 299). Situation awareness, or the lack of it, has been attributed as a causal factor in significant majority of those aviation accidents, in which human error was the major cause, implying the importance of the concept in many other fields of application.

Having been only rarely applied in the field of management (e.g. Bonney et al., 2016), the situation awareness perspective offers tested and practice-based insights that may be applied to business management, and particularly to PSM, which has a salient focus on the external environment. In short, the aim of this paper is (1) to review the situation awareness literature for PSM relevant insights, and (2) to propose a PSM relevant situation awareness model with implications to theory and practice. With these aims, we contribute to the understanding of the microfoundations (e.g. Felin et al., 2012) and components elements of PSM capabilities, such as various resources, routines, and operational and dynamic capabilities (Peng et al., 2008).

2. Takeaways from the situation awareness literature

2.1 Concept of situation awareness

The most broadly accepted definition for situation awareness is the one offered by Endsley (1988, 97; see Stanton et al. 2001): “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” This definition leads to a model of situation awareness, in which corresponding three processes of “situation assessment” contribute to achieving, acquiring and maintaining a state of knowledge, or in other words, situation awareness (Endsley, 1995). These processes are at level 1, perception of elements in the current situation, at level 2, comprehension of current status, and at level 3, projection of future state. Despite some criticism (e.g. Dekker and Hollnagel, 2004), this three-level model of situation awareness has served as a foundation in many studies and fields of application (e.g. Bonney et al., 2016; Golestan et al., 2016; Panteli and Kirschen, 2015; Webb et al., 2014; Fore and Sculli, 2013). Responding to criticism on the model, Endsley (2015) underscores that the three levels are not linear but rather ascending stages, that the model accommodates both data driven (bottom-up) and goal driven (top-down) processing, that both the process (assessment) and the product (awareness) are covered by the model, that the model is dynamic in nature incorporating “ongoing cycles of gathering, interpreting, and projecting information” (Endsley, 2015, 12).

For the benefit of the reader, we provide examples of the levels, drawing on Endsley (1995). The first level or step in achieving situation awareness is “to perceive the status, attributes, and dynamics of relevant elements in the environment…”, and so “a pilot would perceive elements such as aircraft, mountains, or warning lights along with their relevant characteristics (e.g. color, size, speed, location)… a tactical commander needs accurate data on the location, type, number, capabilities and dynamics of all enemy and friendly forces in a given area and their relationships” (p. 36). The second level or step is more than being aware of current elements, as it includes “an understanding of the significance of those elements in light of pertinent operator goals”, and so a “military pilot or tactical commander must comprehend that the appearance of three enemy aircraft within a certain proximity of one another and in a certain geographical location indicates certain things” about the objectives of the operators (Endsley, 1995, 37). Finally, projecting future actions or states of the elements in the environment “at least in the very near term” is the essence of the final level (Endsley, 1995). “…knowing that a threat aircraft is currently offensive and is in a certain location allows a fighter pilot or military commander to project that the aircraft is likely to attack in a given manner”, provides the operators the necessary knowledge to plan actions for meeting their objectives (Endsley, 1995, 37).

In the PSM context, a purchasing manager may observe elements such as suppliers, replenishment deliveries, inventories, internal customers, key performance indicators, and their states, as part of a level 1 process that leads to a basic level of situation awareness. At level 2, the purchasing manager draws on his or her knowledge on the goals and objectives of the PSM function and the category, and understands the significance of the elements and their states. For example, late delivery of key items might be flagged as an important event, a natural disaster at a key source location might be inferred to have implications in terms of availability or global commodity pricing, or the appearance of a new technology at the supply base might be noticed as interesting for the buying firm. At level 3, the purchasing manager, respectively, projects a need for a new supplier, higher commodity price levels in certain time window, and a potentially disruptive effect of the new technology as a key component in the firm’s or its competitors’ products.

2.2 Applicability and relevance of situation awareness

The previously mentioned quotation about the time horizon of projections at level 3 emphasizes mainly the very near term, with situation awareness usually applied to “operational situations”, such as driving a car, treating a patient, directing air traffic (e.g. Fore and Sculli, 2013). However, the literature seems to have also applied the concept for contexts where the urgency of making decisions based on situation awareness (Endsley, 1995) is less pressing, such as in terms of the cyber security (Franke and Brynielsson, 2014) or space (McCormick, 2015). High level of situation awareness in certain contexts might require extending future projections from the “very near term” to short, medium or even long term. Based on the above descriptions, and drawing on the theory on task complexity (e.g. Liu and Li, 2012), it may be that the relevance of developing and maintaining situation awareness increases with increases in detail and dynamic complexity (e.g. Bozarth et al., 2009), as well as the urgency, importance or riskiness of making correct decisions (Panteli and Kirschen, 2015; Gaba and Howard, 1995). For example, multi-casualty incidents with life-and-death decisions (Busby and Witucki-Brown, 2011) have at least higher detail complexity in comparison to single-casualty contexts and they also may score high in terms of urgency, whereas a military context might demonstrate high levels in all the dimensions. Crucially, loss of situational awareness has been suggested as detrimental for system performance (Stanton et al., 2001), and it is likely that high complexity increases the time for additional diagnosis work needed for regaining situation awareness.

The PSM context may demonstrate high detail complexity with many suppliers and items, as well as dynamic complexity with changing requirements, technologies, supply markets etc. The urgency for making operational decisions may not be as high as in nursing (Fore and Sculli, 2013), primary care (Singh et al., 2012), anesthesiology (Gaba and Howard, 1995) or offshore drilling (Sneddon et al., 2006), however, the financial implications of PSM decision for the firm may be high, and in some cases a customer further down the supply chain may suffer as well. The nature of situation awareness required in business contexts may thus be different in comparison to the type that is required in aviation, military or medical care, especially in terms of the third level. In any case, “situation awareness is an integral feature of expert performance in any human endeavor involving the cognitive profile of dynamism, complexity, uncertainty, and risk” (Gaba and Howard, 1995).

Indeed, varying characteristics of contexts may imply different emphasis or nature of the processes that contribute to situational awareness. Webb et al. (2014) focus on information security risk management and suggest three endemic deficiencies in this area with implications to situation awareness. They suggest that “significant sources of risk are not being taken into consideration during the risk management process”, that risk assessment is not evidence-based but rather speculative, and that “information security risk assessment is commonly performed on an intermittent, non-historical basis” (Webb et al., 2014, 3-4), and go on to suggest a situation awareness model that addresses these deficiencies, by proposing comprehensive risk identification, feedback loops for evidence-based risk estimation, and continuous referencing of intelligence for becoming aware of short and long-term trends. Taking into consideration realities in terms of many firms’ resource pools, any practical implementation must for example prioritize efforts, produce actionable intelligence in timely manner and establish trust with the intelligence sources (Webb et al., 2014).

Given the non-strategic nature and status of PSM in many firms (Quayle, 2002; Zheng et al., 2007), it is likely that attention of purchasing managers does not adequately cover all or even the most relevant aspects of the supply market or the internal supply context, the perceived and presented states deviate from the actual state of supply (see Panteli and Kirschen, 2015), and the effort to gather, process and share actionable intelligence market and spend is intermittent at best. In essence, there is likely to be room for improvement in terms of situation awareness of purchasing professionals, especially in terms of access to data, as this is likely to be more unstructured and inaccessible in comparison to for example aviation, where systems and technologies produce a stream of information and alerts. Therefore, the prioritization of efforts for situational awareness is particularly important in PSM where an infinite amount of time could most likely be spent in collecting and analyzing the supply market intelligence.

2.3 Challenges for situation awareness

In the three-level model by Endsley (1988; 1995), there are also certain task/system factors, as well as individual factors that influence the processes contributing to situation awareness, consequent decision making and performance of actions. System capability, interface design, stress and workload, complexity and automation are mentioned as proposed as influential task/system factors, whereas, in addition to the previously mentioned goals and objectives of the operator, information processing mechanisms of individuals, based on abilities, experience and training, influence the situation awareness that can be gained from an input. Furthermore, the difficulty of achieving and maintaining situation awareness have been attributed to eight situation awareness demons (Endsley and Connors, 2008, 2): "(1) attentional narrowing – as humans easily fall prey to attentional narrowing, systems need to support multitasking across multiple goals and decisions; (2) requisite memory trap – systems should not require operators to hold information in memory, since short term memory is limited and easily disrupted; (3) workload, fatigue and other stressors – these factors all act to reduce already limited working memory and disrupt information acquisition; (4) data overload – the volume and rate of change of data in many systems can outpace operators' abilities to keep up with it; (5) misplaced salience – the overuse of prominent visual features such as bright colors and flashing lights overwhelm and misdirect operators' attention; (6) complexity creep – the more complex the system, the harder it is for operators to develop accurate situation comprehension and projection; (7) errant mental models – without good mental models of how a system operates being triggered, it is easy to misinterpret data based on how a different part of the system works; (8) out-of-the-loop syndrome – highly automated systems can leave operators with low awareness of the state of the system." In addition to these more generally applicable sources of difficulty, for example Panteli and Kirschen (2015) summarise factors that govern operator situational awareness in power system control centers. These include environmental factors (graphical user interfaces), automation (reduces workload but excludes the operator), individual factors (experience and training, data and information sharing (inability to coordinate actions), hardware and software applications (critical role), and real-time measurements (delay causes false sense of security). The above factors may also be mapped into a situation awareness error taxonomy, aligned with the three-level model, namely failure to correctly perceive the situation (level 1; e.g. due to data not available or failure to scan), failure to comprehend the situation (level 2; e.g. due to lack of or poor mental model), and failure to project the situation into the future (level 3; e.g. due to lack of or poor mental model).

In the PSM context, some demons are driven by the tendency for fire-fighting in PSM, or the "allocation of scarce resources to solve unanticipated problems" (Repenning, 2001), which may compete and crowd-out attention for detecting changes and opportunities in general, or make managers more inclined to focus on top-down processing, as this is perceived more efficient and time saving (Shepherd et al., 2016). Firefighting may be proposed to drive attentional narrowing (demon 1), increase workload (demon 3), and increase the salience of irrelevant aspects of PSM (demon 5). Proper organization for PSM and category structures and teams may remedy some of the above (Heikkilä and Kaipia, 2009). In terms of demon 4, the problem may in fact be more at the side of data scarcity, as the systems for generating data about the external environment of PSM are yet largely nonexistent, whereas advances have been made in terms of internal spend visibility. With often increasing amount of sourcing areas, suppliers and items (due to product proliferation), complexity creep (demon 6) is likely to be one of the most significant situation awareness demons in PSM. Demon 7 may be remedied with training and encouraging a learning organization (e.g. Senge, 2006). The role of demon 8 may be increasing as automated purchasing systems become more common (Rantala and Hilmola, 2005).

2.4 Improving situation awareness

While domain specific applications for improving situation awareness have been presented in the literature (e.g. Webb et al., 2014; Brady et al., 2013), more general principles have been presented as well, some focusing solely on the human-machine interface design (Endsley, 1995), due to the origins of the concept in aviation. Interestingly, Gaba and Howard (1995) suggest that situation awareness is a generic cognitive skill that can be taught and learned, and that decision makers should remain aware of three aspects of situations, namely subtle cues, evolving situations and special knowledge elements. For detecting and interpreting subtle cues, operators should practice scanning the environment and use checklists, train for allocation of attention by practicing multi-tasking, and train for situation assessment and pattern matching of cues to fault conditions. For adapting to evolving situations, operators must prepare for responding to early cues, and maintain flexibility to avoid, abandon or modify typical standard operating procedures. Special knowledge elements discriminate between the usual situation and the atypical situation, and therefore review of case events with recognition of the case characteristics and the larger context with interdependencies should be undertaken (Gaba and Howard, 1995). Domain-specific insights on improving situation awareness suggest for example the beneficial effect of display design in aircraft cockpits (Andre et al., 1991), inpatient huddles for ensuring addressing of risks (Brady et al., 2013), cross-training in military personnel recovery (Bolstad et al., 2005), and the use of social media in crisis and disaster management context (Yin et al., 2012).

In the PSM context, time and effort should be used in scanning the supply base and market, with templates and plans facilitating the direction of attention in typical multi-tasking contexts. Developing an understanding of typical cause-effect patterns in PSM, and their contingencies, through training, experience and learning, is crucial for assessing situations correctly, reaching high-level situation awareness, and making right decisions for improvement, response and innovation in PSM. Breaking off from standard operating procedures in PSM, may require a certain degree of exploration and ambidextrous orientation (March, 1991) in the function, with top management support establishing the conditions for developing the function. PSM should also be involved in top-management teams and strategic decision making (Tassabehji and Moorhouse, 2008), in order to be exposed to all the relevant information regarding the company and understand the interdependencies of PSM decisions.

3. Applying Endsley's three-level model to PSM

In this section, we consider the Endsley (1995) three-level situation awareness model from the perspective of PSM (Figure 1), by drawing on the above discussion as well as some additional literature.

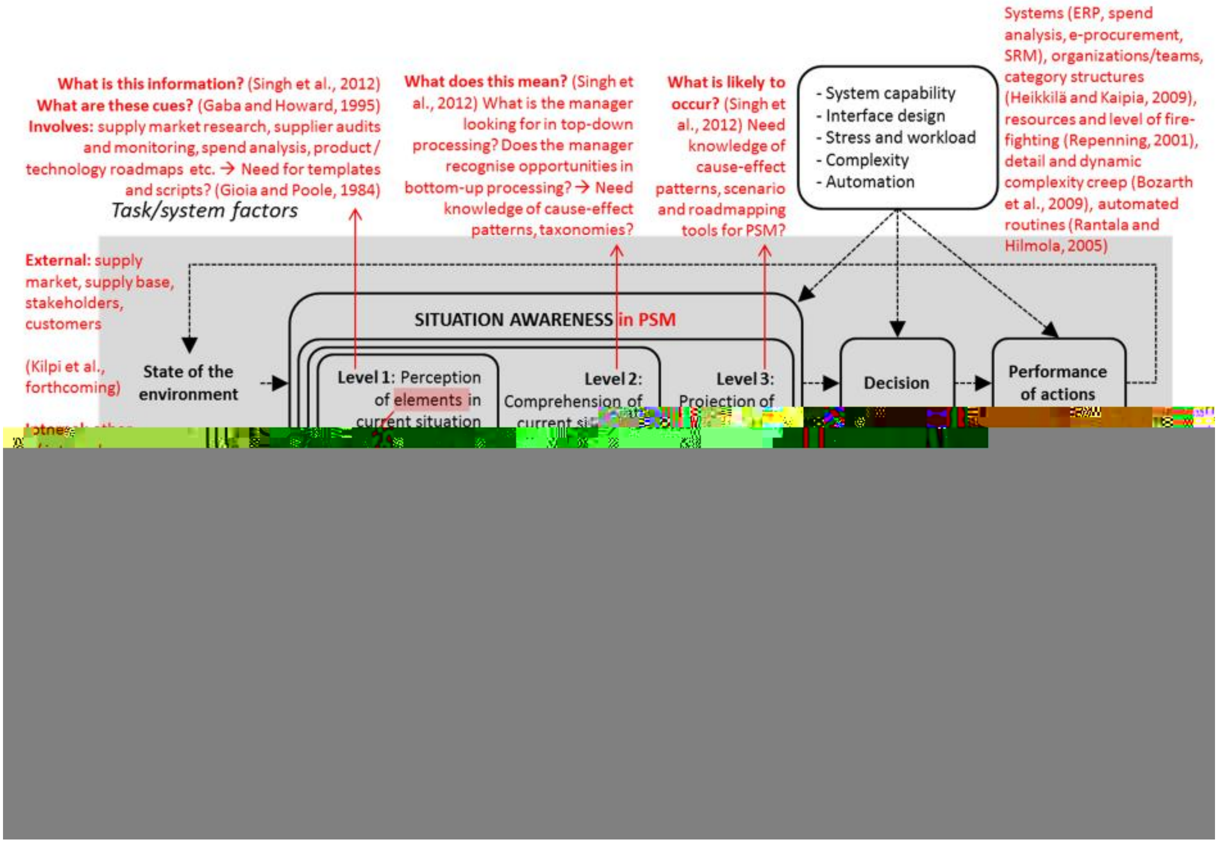

Figure 1 Model of situation awareness in PSM (adapted from Endsley, 1995)

Starting from the left side of the model in Figure 1, the PSM environment may be usefully classified into external and internal, as knowledge acquisition may take place from the supply base (i.e. suppliers used by the buying firm), the broader supply market (all possible suppliers; Kilpi et al.), or from stakeholders and customers. The internal environment comprises other functions in the firm, being in some cases the internal customers, financial context and so forth. Due to the role of PSM as matching external and internal resources for best possible combinations (Tanskanen et al., 2014), the environment to be covered is broad and varied, requiring 360 degree scanning. Furthermore, due to organizational boundaries and for example physical or cultural distance (Berry et al., 2010), access to relevant information about the external or internal environment may also be quite difficult gain. Indeed, the elements of which perception are formed at the level 1 situation assessment, include source locations, suppliers, categories, items and services to be purchased, inventories, deliveries and so forth. The elements themselves or changes therein serve as cues that may subtle and difficult to identify among the noise (Gaba and Howard, 1995). At level 1, the cognitive processes by the purchasing manager are characterized by such questions as “What is this information?” (Singh et al., 2012) and “What are these cues?” (cf. Gaba and Howard, 1995). Routines that contribute to situation awareness at this level may be supply market research, supplier audits and monitoring, spend analysis (Smart and Dudas, 2007), as well as analysis of own and suppliers’ technology and product roadmaps. The concept of supply market intelligence as a routine is often somewhat unstructured in practice, involving many implicit activities, and making the purposeful development of this routine difficult (Lorentz et al., 2016). Therefore, templates or scripts, i.e. “schematic knowledge structure held in memory that specifies behavior or event sequences that are appropriate for specific situations” (Gioia and Poole, 1984), are needed to make the routines associated with level 1 assessment more explicit and as part of the toolbox of purchasing managers.

Level 2 is characterized by questions such as “What does this mean?” (Singh et al., 2012). Here we may also consider the information processing mechanisms that influence situation assessment as individual level factors (Figure 1). On one hand, top-down attentional processing “help top managers achieve efficiency, predictability, and reliability by directing their attention toward aspects of the environment that are expected to reveal potential opportunities and away from aspects that are not expected to be important” (Shepherd et al., 2016). Experience, heuristics and knowledge structures, or cognitive frameworks (McNamara et al., 2002), serve as the “kind of mental template[s] that individuals impose on an information environment to give it form and meaning” (Walsh, 1995, 281). On the other hand, by engaging in more bottom-up attentional processing, “top managers allow the environment to capture attention”, involving “the features and/or properties inherent in the situation that draw attention to themselves even when individuals are not actively searching for them” (Shepherd et al., 2016). Interestingly, theory suggests that the top-down attentional processing is more likely to result in noting incremental changes in the environment, and thus similarly oriented development opportunities or actions, whereas bottom-up attentional processing should be associated with noting discontinuous changes, and thus more radical development opportunities and actions (Shepherd et al., 2016). Furthermore, too much focus on either one may result in missing unexpected signals in the environment, or risking reinventing the wheel and being burdened with complexity, underscoring the importance of appropriately balanced attention allocation (a core issue in the attention-based view; Ocasio, 1997).

It follows that we might ask the following: does the manager recognise opportunities in bottom-up processing, or, what is the manager looking for in top-down processing (Figure 1)? For the first one, the above discussion suggests a need for “mental templates”, and additionally, previous discussion points out the importance of enabling pattern matching of cues to fault conditions and potential remedies and actions (Gaba and Howard, 1995). Here PSM research may contribute to the improvement of practice by attempting to produce taxonomies of fault conditions or failure modes in PSM, as well as further testing and refining taxonomies of levers for improving sourcing performance (Schiele, 2007; Schiele et al., 2011). The aim would be to prepare practitioners better for comprehending the meaning of cues that they perceive in the environment. In terms of top-down processing, the manager is subject to the comprehension of goals and objectives of the PSM function as well as the entire firm (Figure 1). Better knowledge and alignment may be achieved by greater integration, status and involvement in top-level decision making, as well as raising the competence level of the operators of the purchasing and supply system, thereby increasing the purchasing absorptive capacity in the function (Schiele, 2007). Relevantly, the model points out the role of managers’ abilities, experience and training as determinants of several individual factors that influence situation awareness and decision making. Cross-functional job rotation, cross-industry experience, and case-based education prepare managers for better comprehending the situation, as these allow the purchasing managers to understand the internal customer perspective and accumulate skills in pattern matching. It should also be noted that research shows purchasing managers to be liable to several decision making biases, for example concerning source location (country / region) selection (Carter et al., 2008;2010).

Level 3 is characterized with managers asking questions such as “What is likely to occur?” (Singh et al., 2012). The above discussion pointed out the need to go beyond the “very near term”, due to the characteristics of PSM. It might be necessary for the PSM function to project forward up to even medium or long-term, depending on the characteristics of the PSM context in general and the characteristics of critical items or categories in particular. In making projections, managers would again benefit from accumulating cause-effect patterns in their mental model repertoire; however, the PSM practitioners would be likely to benefit from applying scenario planning and customized roadmapping concepts and tools (Phaal and Muller, 2009). The function seems to often suffer from resource scarcity and lack of strategic perspective, making such structured efforts for projection rare.

Finally, the several PSM related task and system level factors influence the process for achieving situation awareness, making decisions and the performance of actions (Figure 1). The capability of the system for example for supporting the processes for situation awareness, include ERP systems, and software for spend analytics, e-procurement and supplier relationship management. These can greatly enhance situation awareness; however, it may be difficult to automate parts of the supply market intelligence routines, making knowledge management systems critically important in order to make the existing knowledge in the organization structured and accessible to others. In human-machine contexts, interface design appears to important, whereas in management contexts, this is substituted by organisations and teams, based on for example category structures that break spend into manageable parts (Heikkilä and Kaipia, 2009), and reduce complexity. In many cases, resource scarcity in PSM causes firefighting (Repenning, 2001), and stress and high workloads, crowding out routines for situation awareness and especially bottom-up information processing (Shepherd et al., 2016). Finally, automation in PSM, for example in terms of replenishment order generation (Rantala and Hilmola, 2005), is a double-edged sword, giving managers more time for complicated routines, but simultaneously risking excluding managers from the loop and reducing situation awareness and intervention ability in failure modes (Endsley and Kiris, 1995).

4. Conclusions and implications

This paper makes a contribution to the PSM literature by reviewing the situation awareness literature for PSM relevant insights, and by proposing a PSM relevant situation awareness model with implications to theory and practice. The review considered the concept of situation awareness, its applicability and relevance in various contexts, the challenges for achieving situation awareness, and the aspects of improving situation awareness. It is concluded that despite PSM differing from the usual contexts of application of the situation awareness concept, many of its potential characteristics make it a highly relevant perspective for purchasing professionals. Routines that underlie and contribute to situation awareness, may be classified as for example “search routines”, as they the execution of such procedures “bring about desirable changes in the existing set of operating routines or developing new ones” (Peng et al., 2008). And as such, they contribute to dynamic capabilities in PSM, as the “ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments” (Teece et al., 1997). In essence, situation awareness enables PSM function to adapt to the environment, and retain its relevance and reach its strategic potential. It is suggested that future research should address the microfoundations of dynamic capabilities in PSM, potentially drawing on the situation awareness concept.

By elaborating the three-level model of situation awareness (Endsley, 1995) from the PSM perspective, we further pointed out its relevance for this domain, and focused attention on the individual as a decision maker and change agent in PSM. The model raises awareness of the routines, individual and task characteristics that enable decision making and high-performance action, and ultimately the success of a purchasing manager. As such, the situation awareness concept and our elaborations, should be interesting to practitioners, by pointing out the necessity of supporting routines, and for researchers, by suggesting further research on the individual as a microfoundation of PSM capability (Felin et al., 2012).

As further research, we suggest to address all the underlying routines for supporting level 1, 2 and 3 assessments for greater situation awareness. First, research should develop frameworks and scripts for collecting, analyzing and distributing supply market intelligence, as the knowledge base in this area is quite immature. Second, the taxonomy of sourcing levers, elaborated by Schiele (2007), should be refined and tested, and integrated into practical tools such as category cards, as enablers of developing sourcing tactics and improved opportunity perception. Third, a roadmapping concept for future oriented development in PSM should be conceptualized and developed into a practical tool. First practical attempts by the authors in this regard indicate great interest from companies and suggest that a successful application includes both demand and supply market future projections (e.g. 5 years forward), which are then linked with understandings on corresponding internal customer requirements, supplier base development plans, as well as PSM function capability development plans in a timeline. With raising awareness and applying the to-be-developed concepts and tools, situation awareness can be raised in individual purchasing managers as well as in PSM teams, with beneficial effects on decisions and performance.

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5.2 Differences in skills of the total operation of delivery staffs in case sites (Step 2-3)

The following data are the differences in skills of the total operation of delivery staffs in case sites. Table 1 and 2 shows the differences in skills of the total operation of delivery personnel. Table 1 indicates staffs of maximum and minimum differences of each staff. Staff *b* and *i* are totally the staff of the maximum differences of each staff. A combination of staffs of the largest differences is staff *e* & *i* from Table 2. They has four skills of the large difference, *size*, *amount of load*, *daily inspection* and *a check for going into customer's home*. A combination of staffs of the smallest differences is staff *m* & *n*.

Table 1. Differences in the observations of delivery personnel ($x_{t1:t2}$)

Difference / Staff(*t1*)	Maximum		Minimum	
	Staff(*t2*)	$X_{t1:t2}$	Staff (*t2*)	$X_{t1:t2}$
a	i	23.0	m, n	11.0
b	c, o	26.0	a	14.0
c	b	26.0	d	5.0
d	b	21.0	c, h	5.0
e	i	27.0	d	7.0
f	i	24.0	i	12.0
g	b	24.0	n	3.0
h	b	24.0	d	5.0
i	e	27.0	l	18.0
j	i	25.0	m, n	7.0
k	i	23.0	j	10.0
l	b	23.0	h	7.0
m	i	24.0	n	2.0
n	i	26.0	m	2.0
o	b	26.0	l	11.0

Table 2. Differences in the observations of all delivery personnel ($x_{t1:t2}$)

Staff / Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
a		14.0	16.0	13.0	16.0	17.0	12.0	14.0	23.0	12.0	14.0	15.0	11.0	11.0	20.0
b	14.0		26.0	21.0	20.0	23.0	24.0	24.0	21.0	22.0	22.0	23.0	21.0	23.0	26.0
c	16.0	26.0		5.0	10.0	17.0	8.0	6.0	25.0	12.0	14.0	9.0	7.0	7.0	12.0
d	13.0	21.0	5.0		7.0	14.0	7.0	5.0	20.0	11.0	13.0	8.0	8.0	8.0	13.0
e	16.0	20.0	10.0	7.0		17.0	12.0	10.0	27.0	16.0	14.0	13.0	13.0	13.0	16.0
f	17.0	23.0	17.0	14.0	17.0		15.0	15.0	24.0	17.0	19.0	12.0	14.0	16.0	19.0
g	12.0	24.0	8.0	7.0	12.0	15.0		8.0	23.0	8.0	12.0	9.0	5.0	3.0	16.0
h	14.0	24.0	6.0	5.0	10.0	15.0	8.0		21.0	8.0	12.0	7.0	7.0	9.0	14.0
i	23.0	21.0	25.0	20.0	27.0	24.0	23.0	21.0		25.0	23.0	18.0	24.0	26.0	19.0
j	12.0	22.0	12.0	11.0	16.0	17.0	8.0	8.0	25.0		10.0	13.0	7.0	7.0	18.0
k	14.0	22.0	14.0	13.0	14.0	19.0	12.0	12.0	23.0	10.0		17.0	11.0	11.0	18.0
l	15.0	23.0	9.0	8.0	13.0	12.0	9.0	7.0	18.0	13.0	17.0		8.0	10.0	11.0
m	11.0	21.0	7.0	8.0	13.0	14.0	5.0	7.0	24.0	7.0	11.0	8.0		2.0	15.0
n	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	11.0	10.0	2.0		17.0
o	20.0	26.0	12.0	13.0	16.0	19.0	16.0	14.0	19.0	18.0	18.0	11.0	15.0	17.0	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 3 and 4 shows the differences in skills of the total operation of delivery personnel and supervisors. Table 3 indicates staffs of maximum and minimum differences of each supervisor. Staff *b* and *i* are the staff of the maximum difference of each supervisor. Staff *g* and *n* are the staff of the minimum difference of each supervisor. A combination of staff and

supervisor of the largest difference is staff *b* & supervisor *ε* from Table 4. They has four skills of the large difference, *amount of load, classification of delivery routes, positon of package* and *the direction of the package when deliver to a customer*. A combination of staff and supervisor of the smallest difference is staff *n* & supervisor *Δ*.

Table 3. Differences in the observations of delivery personnel and supervisors ($x_{s:t}$)

Supervisor(s) \ Difference	Maximum		Minimum	
	Staff (*t*)	$X_{s:t}$	Staff (*t*)	$X_{s:t}$
α	*i*	27.0	*n*	3.0
B	*i*	29.5	*g, n*	13.5
γ	*i*	27.0	*g*	7.0
Δ	*i*	26.0	*n*	2.0
ε	*b*	30.5	*n*	12.5

Table 4. Differences in the observations of all delivery personnel and all supervisors ($x_{s:t}$)

Supervisor \ Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
α	11.0	22.0	8.0	9.0	13.0	16.0	4.0	10.0	27.0	8.0	9.0	11.0	5.0	3.0	18.0
β	18.5	24.5	18.5	17.5	21.5	20.5	13.5	20.5	29.5	18.5	20.5	17.5	15.5	13.5	22.5
γ	13.0	24.0	12.0	11.0	17.0	19.0	7.0	14.0	27.0	17.0	17.0	15.0	13.0	11.0	15.0
Δ	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	9.0	10.0	4.0	2.0	17.0
ε	21.5	30.5	15.5	16.5	20.5	21.5	13.5	17.5	29.5	17.5	17.5	16.5	14.5	12.5	22.5

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 5 and 6 shows the differences in skills of the total operation of supervisors. Table 5 indicates supervisors of maximum and minimum differences of each supervisors. Supervisor *β* and *ε* are the supervisor of the maximum difference of each supervisor. A combination of supervisors of the largest difference is supervisor *β* & *ε* from Table 6. They has two skills of the large difference, *original delivery routes* and c*lassification of delivery routes*. A combination of staffs of the smallest differences is supervisor α & Δ.

Table 5. Differences in the observations of supervisors ($x_{s1:s2}$)

Supervisor(s1) \ Difference	Maximum		Minimum	
	Supervisor(*s2*)	$X_{s1:s2}$	Supervisor(*s2*)	$X_{s1:s2}$
α	*β*	12.5	*Δ*	1.0
B	*ε*	13.0	*γ, Δ*	11.5
γ	*ε*	12.5	*α, Δ*	5.0
Δ	*β*	11.5	*A*	1.0
ε	*β*	13.0	*Δ*	10.5

Table 6. Differences in the observations of all supervisors ($x_{s1:s2}$)

Supervisor \ Supervisor	α	β	γ	Δ	ε
α		12.5	5.0	1.0	11.5
β	12.5		11.5	11.5	13.0
γ	5.0	11.5		5.0	12.5
Δ	1.0	11.5	5.0		10.5
ε	11.5	13.0	12.5	10.5	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

6. Discussion

'Mizusumashi' aims to the just-in-time operation, only the necessary items in the necessary quantities at the necessary time (Ichikawa 2009). This paper considers that 48 skills of the home delivery are put for four ideal situations, necessary item, necessary quantities and necessary time and others in Table 7. Most skills are related to necessary time before arriving customer's home. Also, delivery staffs naturally needs to consider attributes of packages when preparing, loading and giving them. A dairy inspection and a manner at customer's home will be important for all three performances of just-in time operation.

Table 7. A relationship between ideal situation and skills in home-delivery operation

Ideal situation / Home-delivery operation	Necessary items	Necessary quantities	Necessary time	Others
I Decision and mapping of delivery routes	● Shape of package ● Attribute of customer	● A number of package	● A load per a day ● Estimated delivery time ● Designated date and time ● Designated address ● Classification of delivery routes ● Original delivery routes ● Closing da of customer ● Tendency of absence ● Customer's at-home time ● Delivery order	
II Efficient loading of deliverables onto a vehicle	● Size ● Wight ● Shape ● Alerting ● Damage of package	● Number of one customer	● Amount of load ● Positon of package ● In case of not loading planned all packages ● In case of being enough space in vehicle ● Change of weather	
III Focused driving			● Traffic rule ● State of road surface ● Utilization state of road ● Attention of walkers, bicycles and cars ● The way of stop ● The place where stop ● When bad weather	● Daily Inspection ● Roll-calling
IV Timely and hospitality deliver of the package to the customer	● Delivered package ● Safety delivery ● A check for going into customer's home ● A place to put a package ● Direction ● One voice ● Confirmation of delivery ● Sign of delivery	● Weigh		● Noise ● Neighbors ● Neighborhood ● A manner in customer's home

The result obtained from the analysis in the previous section shows that logistic capabilities of staff *b* and staff *i* are different from other staffs and supervisors. In the future problem of the academic side, a mathematical model for optimizing a combination for a pair-training and a pair-work will be designed. A dealing of the values of the two staffs are considered in the design.

7. Concluding remarks

This study suggests the essential skills for the proper operation with a tricycle, a typical small vehicle with a short turning radius like 'Mizusumashi' in Toyota Production System. As the result of an extraction of factors of the objective operation through several discussions between a home delivery expert and an academic researcher, 48 deduced factors are categorised under 4 main operations: I) decision and mapping of the delivery routes, II) efficient loading of deliverables onto a vehicle, III) focused driving, and IV) timely and hospitality delivery of the package to the customer. Moreover, a questionnaire is developed, incorporating the systematized factors. Subsequently, the relevant feedback of workers of case sites are investigated by the questionnaire, and the differences in the observations of the delivery personnel and supervisors are registered. Through the discussion based on the result of the questionnaire, the future direction of this study is considered compared with 'Mizusumashi' operation. These findings will be the basic data for the effective training and education of home delivery operations in the future.

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Table 1. Differences in the observations of delivery personnel ($x_{t1:t2}$)

Difference / Staff(*t1*)	Maximum		Minimum	
	Staff(*t2*)	$X_{t1:t2}$	Staff (*t2*)	$X_{t1:t2}$
a	i	23.0	m, n	11.0
b	c, o	26.0	a	14.0
c	b	26.0	d	5.0
d	b	21.0	c, h	5.0
e	i	27.0	d	7.0
f	i	24.0	i	12.0
g	b	24.0	n	3.0
h	b	24.0	d	5.0
i	e	27.0	l	18.0
j	i	25.0	m, n	7.0
k	i	23.0	j	10.0
l	b	23.0	h	7.0
m	i	24.0	n	2.0
n	i	26.0	m	2.0
o	b	26.0	l	11.0

Table 2. Differences in the observations of all delivery personnel ($x_{t1:t2}$)

Staff / Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
a		14.0	16.0	13.0	16.0	17.0	12.0	14.0	23.0	12.0	14.0	15.0	11.0	11.0	20.0
b	14.0		26.0	21.0	20.0	23.0	24.0	24.0	21.0	22.0	22.0	23.0	21.0	23.0	26.0
c	16.0	26.0		5.0	10.0	17.0	8.0	6.0	25.0	12.0	14.0	9.0	7.0	7.0	12.0
d	13.0	21.0	5.0		7.0	14.0	7.0	5.0	20.0	11.0	13.0	8.0	8.0	8.0	13.0
e	16.0	20.0	10.0	7.0		17.0	12.0	10.0	27.0	16.0	14.0	13.0	13.0	13.0	16.0
f	17.0	23.0	17.0	14.0	17.0		15.0	15.0	24.0	17.0	19.0	12.0	14.0	16.0	19.0
g	12.0	24.0	8.0	7.0	12.0	15.0		8.0	23.0	8.0	12.0	9.0	5.0	3.0	16.0
h	14.0	24.0	6.0	5.0	10.0	15.0	8.0		21.0	8.0	12.0	7.0	7.0	9.0	14.0
i	23.0	21.0	25.0	20.0	27.0	24.0	23.0	21.0		25.0	23.0	18.0	24.0	26.0	19.0
j	12.0	22.0	12.0	11.0	16.0	17.0	8.0	8.0	25.0		10.0	13.0	7.0	7.0	18.0
k	14.0	22.0	14.0	13.0	14.0	19.0	12.0	12.0	23.0	10.0		17.0	11.0	11.0	18.0
l	15.0	23.0	9.0	8.0	13.0	12.0	9.0	7.0	18.0	13.0	17.0		8.0	10.0	11.0
m	11.0	21.0	7.0	8.0	13.0	14.0	5.0	7.0	24.0	7.0	11.0	8.0		2.0	15.0
n	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	11.0	10.0	2.0		17.0
o	20.0	26.0	12.0	13.0	16.0	19.0	16.0	14.0	19.0	18.0	18.0	11.0	15.0	17.0	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 3 and 4 shows the differences in skills of the total operation of delivery personnel and supervisors. Table 3 indicates staffs of maximum and minimum differences of each supervisor. Staff *b* and *i* are the staff of the maximum difference of each supervisor. Staff *g* and *n* are the staff of the minimum difference of each supervisor. A combination of staff and

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Table 3. Differences in the observations of delivery personnel and supervisors ($x_{s:t}$)

Supervisor(s) \ Difference	Maximum		Minimum	
	Staff (*t*)	$X_{s:t}$	Staff (*t*)	$X_{s:t}$
α	*i*	27.0	*n*	3.0
B	*i*	29.5	*g, n*	13.5
γ	*i*	27.0	*g*	7.0
⊿	*i*	26.0	*n*	2.0
ε	*b*	30.5	*n*	12.5

Table 4. Differences in the observations of all delivery personnel and all supervisors ($x_{s:t}$)

Supervisor \ Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
α	11.0	22.0	8.0	9.0	13.0	16.0	4.0	10.0	27.0	8.0	9.0	11.0	5.0	3.0	18.0
β	18.5	24.5	18.5	17.5	21.5	20.5	13.5	20.5	29.5	18.5	20.5	17.5	15.5	13.5	22.5
γ	13.0	24.0	12.0	11.0	17.0	19.0	7.0	14.0	27.0	17.0	17.0	15.0	13.0	11.0	15.0
Δ	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	9.0	10.0	4.0	2.0	17.0
ε	21.5	30.5	15.5	16.5	20.5	21.5	13.5	17.5	29.5	17.5	17.5	16.5	14.5	12.5	22.5

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 5 and 6 shows the differences in skills of the total operation of supervisors. Table 5 indicates supervisors of maximum and minimum differences of each supervisors. Supervisor *β* and *ε* are the supervisor of the maximum difference of each supervisor. A combination of supervisors of the largest difference is supervisor *β* & *ε* from Table 6. They has two skills of the large difference, *original delivery routes* and c*lassification of delivery routes*. A combination of staffs of the smallest differences is supervisor α & Δ.

Table 5. Differences in the observations of supervisors ($x_{s1:s2}$)

Supervisor(s1) \ Difference	Maximum		Minimum	
	Supervisor(*s2*)	$X_{s1:s2}$	Supervisor(*s2*)	$X_{s1:s2}$
α	*β*	12.5	*⊿*	1.0
B	*ε*	13.0	*γ, ⊿*	11.5
γ	*ε*	12.5	*α, ⊿*	5.0
⊿	*β*	11.5	*A*	1.0
ε	*β*	13.0	*⊿*	10.5

Table 6. Differences in the observations of all supervisors ($x_{s1:s2}$)

Supervisor \ Supervisor	α	β	γ	Δ	ε
α		12.5	5.0	1.0	11.5
β	12.5		11.5	11.5	13.0
γ	5.0	11.5		5.0	12.5
Δ	1.0	11.5	5.0		10.5
ε	11.5	13.0	12.5	10.5	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

6. Discussion

‘Mizusumashi’ aims to the just-in-time operation, only the necessary items in the necessary quantities at the necessary time (Ichikawa 2009). This paper considers that 48 skills of the home delivery are put for four ideal situations, necessary item, necessary quantities and necessary time and others in Table 7. Most skills are related to necessary time before arriving customer’s home. Also, delivery staffs naturally needs to consider attributes of packages when preparing, loading and giving them. A dairy inspection and a manner at customer’s home will be important for all three performances of just-in time operation.

Table 7. A relationship between ideal situation and skills in home-delivery operation

Ideal situation / Home-delivery operation	Necessary items	Necessary quantities	Necessary time	Others
I Decision and mapping of delivery routes	● Shape of package ● Attribute of customer	● A number of package	● A load per a day ● Estimated delivery time ● Designated date and time ● Designated address ● Classification of delivery routes ● Original delivery routes ● Closing da of customer ● Tendency of absence ● Customer’s at-home time ● Delivery order	
II Efficient loading of deliverables onto a vehicle	● Size ● Wight ● Shape ● Alerting ● Damage of package	● Number of one customer	● Amount of load ● Positon of package ● In case of not loading planned all packages ● In case of being enough space in vehicle ● Change of weather ● Traffic rule	
III Focused driving			● State of road surface ● Utilization state of road ● Attention of walkers, bicycles and cars ● The way of stop ● The place where stop ● When bad weather	● Daily Inspection ● Roll-calling
IV Timely and hospitality deliver of the package to the customer	● Delivered package ● Safety delivery ● A check for going into customer’s home ● A place to put a package ● Direction ● One voice ● Confirmation of delivery ● Sign of delivery	● Weigh		● Noise ● Neighbors ● Neighborhood ● A manner in customer’s home

The result obtained from the analysis in the previous section shows that logistic capabilities of staff *b* and staff *i* are different from other staffs and supervisors. In the future problem of the academic side, a mathematical model for optimizing a combination for a pair-training and a pair-work will be designed. A dealing of the values of the two staffs are considered in the design.

7. Concluding remarks

This study suggests the essential skills for the proper operation with a tricycle, a typical small vehicle with a short turning radius like 'Mizusumashi' in Toyota Production System. As the result of an extraction of factors of the objective operation through several discussions between a home delivery expert and an academic researcher, 48 deduced factors are categorised under 4 main operations: I) decision and mapping of the delivery routes, II) efficient loading of deliverables onto a vehicle, III) focused driving, and IV) timely and hospitality delivery of the package to the customer. Moreover, a questionnaire is developed, incorporating the systematized factors. Subsequently, the relevant feedback of workers of case sites are investigated by the questionnaire, and the differences in the observations of the delivery personnel and supervisors are registered. Through the discussion based on the result of the questionnaire, the future direction of this study is considered compared with 'Mizusumashi' operation. These findings will be the basic data for the effective training and education of home delivery operations in the future.

Acknowledgments

This research was undertaken with the support of the case-study case site. We sincerely thank the shop and its staff for providing valuable data. Ms. Haruka Tsujii also positively supported to collect data and prepare interviews in this research as a member of our laboratory. This paper was also supported by JSPS KAKENHI Grant Number JP 16K03897.

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Skills design of home delivery operations by tricycle: For improving service quality in last mile stage

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Abstract
This study suggests that the essential skills for the proper operation with a tricycle, a typical small vehicle with a short turning radius like 'Mizusumashi' in Toyota Production System, is necessary to improve service quality in last mile stage of home delivery. This study uses an inductive approach. It is an extraction of factors of the objective operation through several discussions between a home delivery expert and an academic researcher. As the result of the study, 48 deduced factors are categorised under 4 main operations: I) decision and mapping of the delivery routes, II) efficient loading of deliverables onto a vehicle, III) focused driving, and IV) timely and hospitality delivery of the package to the customer. Moreover, a questionnaire is developed, incorporating the systematized factors. Subsequently, the relevant feedback of workers of case sites are investigated by the questionnaire, and the differences in the observations of the delivery personnel and supervisors are registered. These findings will be the basic data for the effective training and education of home delivery operations in the future.

Keywords: Last mile, Home delivery operation, Small vehicle and Skills design, Mizusumashi.

1. Introduction
Home-delivery orders have increased drastically over the last few years in Japan due to internet shopping by end users. After leaving central distribution centre of a retail company as shown in Figure 1, ordered package is mainly transported to orderer's house via two transfer points such as a distribution centre of main city where an orderer lives and a collection and distribution site close to orderer's house. In particular, the performance of the total transportation system depends on the delivery in the last mile stage because the operation have a direct influence on customer impression. However, with regards to the collection and delivery site, the lack of education and training in how to use a small vehicle with a short turning radius for delivering within a residential area poses problems such as driving in narrow lanes. Furthermore, inexperienced delivery personnel learn the necessary job skills from the individual methodology of each senior delivery staff member and, as a result, discrepancies in the techniques and skills of home delivery surface. This is a serious situation, especially when there is an increase in hastily unemployed persons and it is feared that the quality of the delivery service will decrease.
Based on the above recognitions, as an initial step for improving the current situation, this study suggests that the essential skills for the proper operation with a tricycle, a typical small vehicle with a short turning radius like 'Mizusumashi' in Toyota Production System, is necessary. This paper consists of the following seven sections. Related literature of the last mile distribution and focused cases are reviewed in the next section. A research procedure is illustrated in the third section. A result of the study is described in the fourth, fifth and sixth sections, and conclusions are given in the final section.

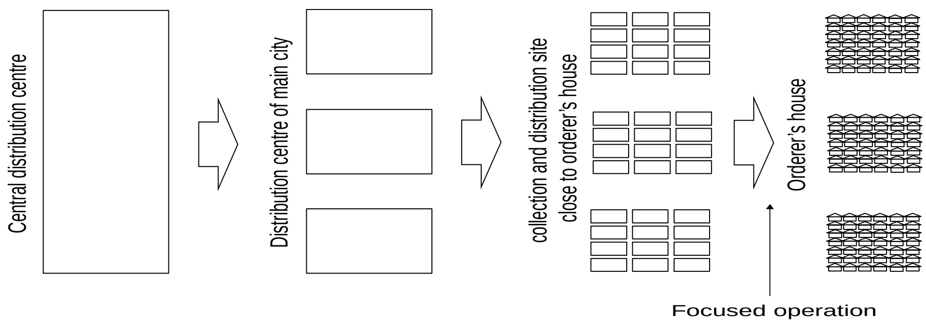


Figure 1. Transportation system considered in this paper and operation focused in the system

2. Research Background

2.1 Related literature

Three related literature have been investigated in the beginning to the research followed by the structure as shown in Figure 2. They are 1) last mile distribution, 2) logistics capability and 3) 'Mizusumashi' operation.

The first one is about the problem focused in this paper. The general way to get products by customers is traditional shopping at stores or home-delivery shopping. Last-mile deliveries are considered as the latter type (Boyer 2004, Balclk 2008). Balclk (2008) suggested that it is necessary to consider the innovation of this function of the supply chain from three levels of the value of supplied product (low value, medium value and high value). Important activities are also arranged every values of the product from five viewpoints, consumer service, security & delivery type, geographical & market density/penetration, fleet & technology and the environment. The problem of the last-mile distribution also determines 1) delivery schedules, 2) vehicle routes and 3) the amount of emergency supplies delivered to demand locations during disaster relief operations (Gevaers 1985). In particular, Gevaers (1985) attempted to resolve third problem by integer programming model.

The second one is about the base to improve a quality of the last-mile distribution mentioned above. Most of the related studies has used statistical analysis. Cho (2008) analyzed the relationship among firm's logistics capability, logistics outsourcing and its performance in an e-commerce market environment. Fawcett (1997) clarified the relationship between logistics capability and logistics performance under the globalization. Tan (1997) focused a structure of the linkage between operational capability and financial performance via service quality to evaluate supply chain performance. However there are a few studies of logistics capability focused in last-mile distribution.

The third one is about the hint to consider the last-mile operation. 'Mizusumashi' has been used in Toyota Production System (TPS) (Ohno 1988). Vad (2014) illustrates that 'Mizusumashi', a Japanese word for Water Spider, is a person who manages the replenishment tasks to workstations in order to minimize work-in-process inventories. Ichikawa (2009) also reports that the work by a material handler strongly affects overall productivity of the assemble cells by just-in-time operation. When comparing last-mail operation to 'Mizusumashi' operation, a delivery staff is a material handler, customers' home are workstations. To be sure, service quality of last-mile operation must be just-in-time level.

Based on the above literature review, this paper investigates current situation of the frontline of last-mail distribution.

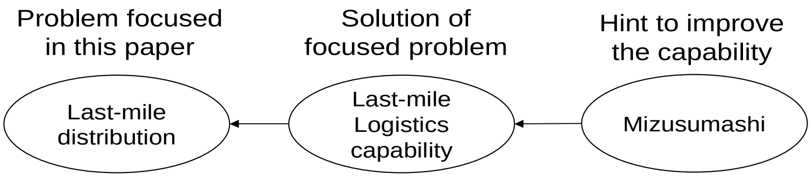


Figure 2. Structure of related literature

2.2 Case site

Case company of this study is one representative third-party logistics company in Japan. The main service is a logistics to business to customer (B-to-C). They recently emphasize to develop environmental-friendly vehicles except a track, a tricycle, in home-delivery service in urban area. The object of this paper is home-delivery distribution with a tricycle in case site of the company.

3. Research Procedure

The research procedure of this paper mainly consists of the following two steps as shown in Figure 3. The first step is an extraction of factors of the objective operation through several discussions between a home delivery expert and an academic researcher. Extracted factors are arranged to one tree diagram. The second step has three sub-steps. The first sub-step is a development of a questionnaire, incorporating the systematized factors. The second sub-step is an investigation of the relevant feedback of workers of case sites by the questionnaire. And the last sub-step is a registration of the differences in the observations of the delivery personnel and supervisors to manage the delivery personnel.

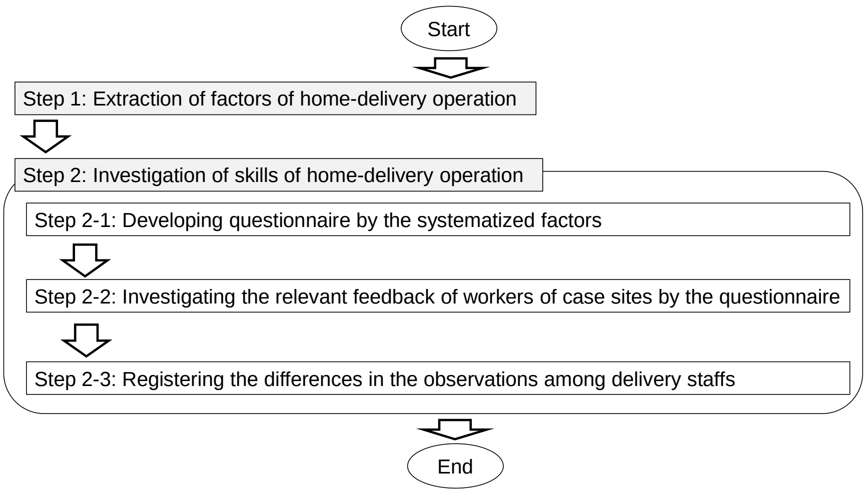


Figure 3. Research procedure of this paper

In step 2-3, the following three equations are used to calculate differences in the observations of delivery personnel and supervisors.

1) Differences in the observations of delivery personnel

$$x_{t_1:t_2}^{ij} = \left| m_{t_1 ij} - m_{t_2 ij} \right| \; (i = 1, \dots, o, j = 1, \dots, \mathrm{p}, t_1, t_2 = 1, \dots, \mathrm{q}) \tag{1}$$

(Differences in skill *j* of category *i* of two delivery staffs)

2) Differences in the observations of delivery personnel and supervisors

$$x_{s:t}^{ij} = \left| m_{tij} - e_{sij} \right| (i = 1, \dots, o, j = 1, \dots, \mathrm{p}, t = 1, \dots, \mathrm{q}, \mathrm{s} = 1, \dots, \mathrm{r}) \tag{2}$$

(Differences in skill *j* of category *i* of delivery staff *t* and supervisor *s*)

3) Differences in the observations of supervisors

$$x_{s_1:s_2}^{ij} = \left| e_{s_1 ij} - e_{s_2 ij} \right| (i = 1, \dots, o, j = 1, \dots, \mathrm{p}, s_1, s_2 = 1, \dots, \mathrm{r}) \tag{3}$$

(Differences in skill *j* of category *i* of two supervisors)

<Notation>

m_{tij} : Self-assessment in home-delivery skill *j* of category *i* of staff *t*
e_{sij} : Self-assessment in home-delivery skill *j* of category *i* of supervisor *s*
o : A total number of categories of home-delivery skill
p : A total number of skills
q : A total number of staffs
r : A total number of supervisors
i : A suffix of category of home-delivery skill
j : A suffix of home-delivery skill
t : A suffix of staff
s : A suffix of supervisor

4. Factors of the proper operation for home-delivery (Step 1)

As the result of the first step of this research, Figure 4 illustrates tree diagram for home-delivery operation with a tricycle. This diagram consists of four main operations of home delivery, I) Decision and mapping of delivery routes, II) Efficient loading of deliverables onto a vehicle, III) Focused driving and IV) Timely and hospitality deliver of the package to the customer. Each operation has the viewpoints of two levels to extract the related skills (In the following description, a viewpoint of the first level uses single quotation marks and a viewpoint of the second level uses double quotation marks).

In the first main operation, the viewpoints of the first level are ‘a package’ and ‘a delivery’. The former one of the viewpoint of the second level has “a total of deliverables” and “every packages”. The latter one of that has “delivery routes” and “avoidance of go back without delivery”. In the second main operation, the viewpoints of the first level are ‘a package’ and ‘know-how to load’. The former one of the viewpoint of the second level has “physical characteristics” and “prevention of damage”. In the third main operation, the viewpoints of the first level are ‘before driving’ and ‘In driving’. The latter one of the viewpoint of the second level has “route information” and “safety information”. In the fourth main operation, the viewpoint of the first level are ‘surrounding environment’ and ‘a package’. The former one of the viewpoint of the second level has “neighborhood of customer’s home” and “customer’s home”.

Through the deployment of the home-delivery operation, 48 skills are extracted as shown in Figure 5. A number of skills of each main operation are 12, 11, 12 and 13.

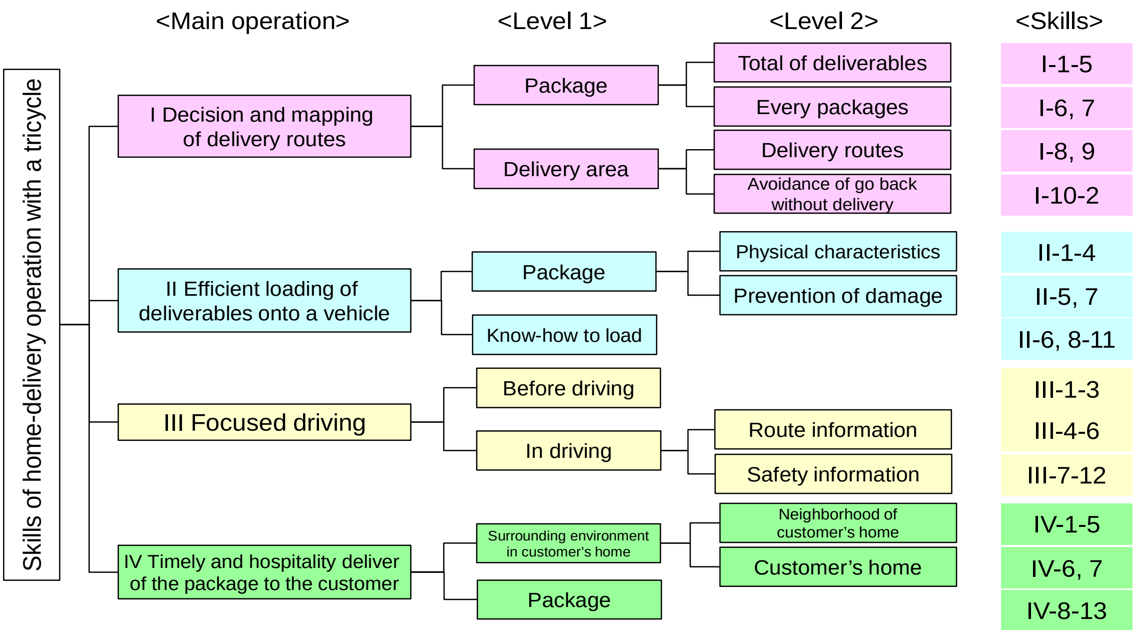


Figure 4. Tree diagram for home-delivery operation with a tricycle

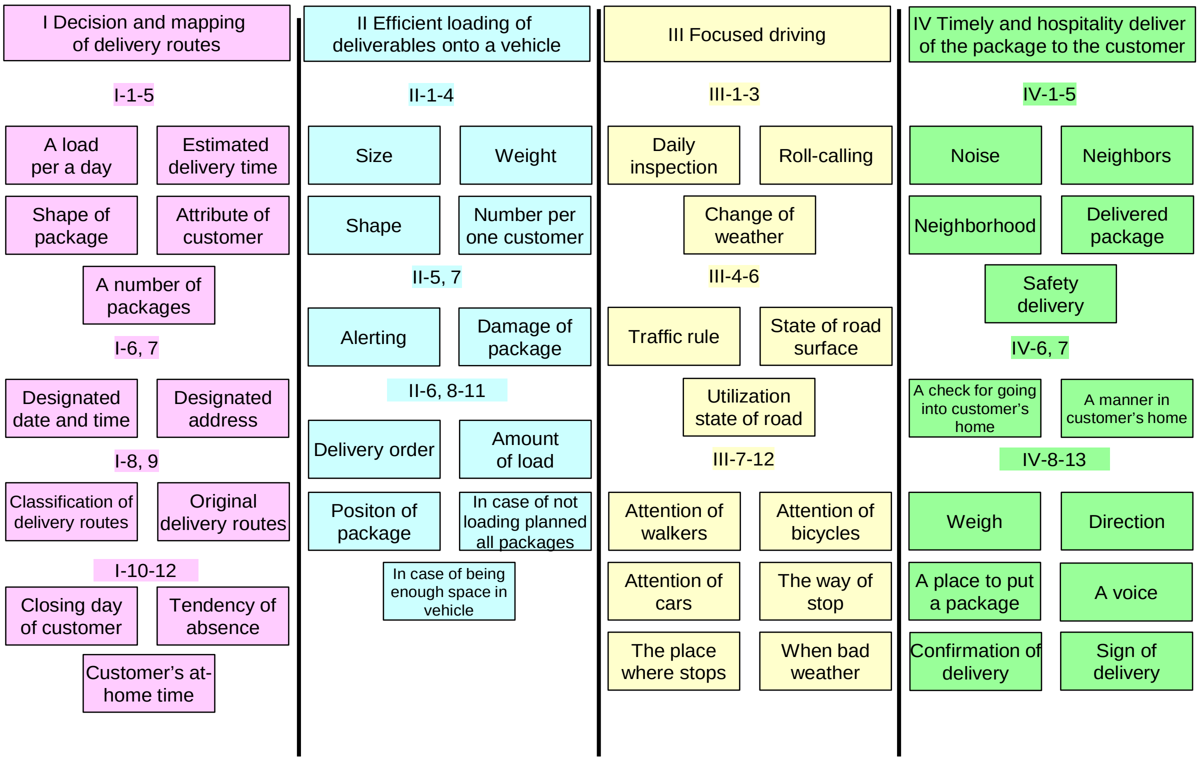


Figure 5. Keywords of 48 extracted skills

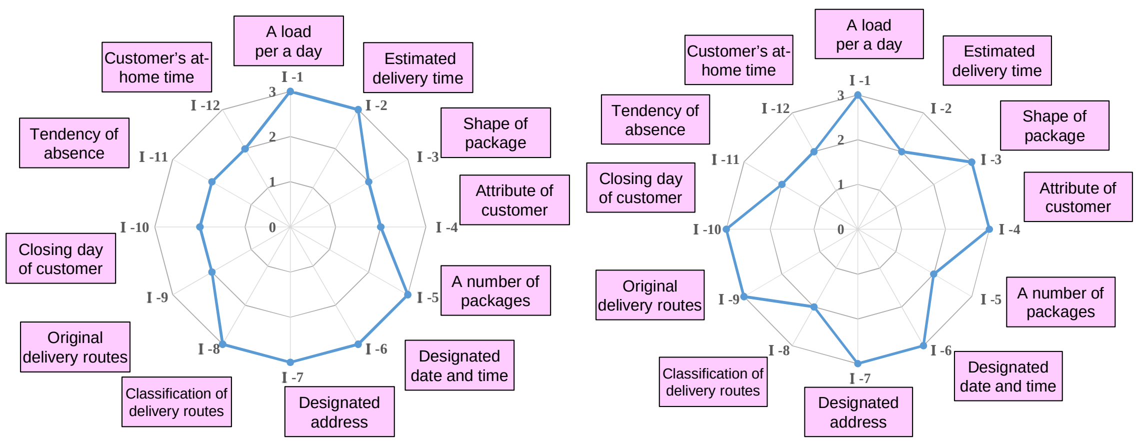
5. Differences in the observation among delivery staffs of case sites

5.1 Design of questionnaire and investigation by designed questionnaire (Step 2-1&2)

The purpose of the questionnaire is to grasp the recognition of delivery staffs in their daily operation. 48 questions are designed to all 48 skills one by one. One question has three choices of a skill (necessary, little necessary and not necessary).

Respondents of the questionnaire are staffs of case sites. Staffs are divided into two kinds such as delivery personnel and supervisors. A number of delivery personnel is 15 and that of supervisors is 5. A way of the investigation is self-check with the researcher who well knows the respondents at case site.

The partial result of the investigation shows Figure 6. Two charts are for staff *e* and staff *i*. They indicates that their 12 skills of the operation for decision and mapping of delivery routes. There are totally differences in the shape of two radar charts. Therefore there are differences in skills of the operation of two staffs



Left side: Staff *e* Right side: Staff *i*

Figure 6. Radar charts of the operation for decision and mapping of delivery routes

5.2 Differences in skills of the total operation of delivery staffs in case sites (Step 2-3)

The following data are the differences in skills of the total operation of delivery staffs in case sites. Table 1 and 2 shows the differences in skills of the total operation of delivery personnel. Table 1 indicates staffs of maximum and minimum differences of each staff. Staff *b* and *i* are totally the staff of the maximum differences of each staff. A combination of staffs of the largest differences is staff *e* & *i* from Table 2. They has four skills of the large difference, *size*, *amount of load*, *daily inspection* and *a check for going into customer's home*. A combination of staffs of the smallest differences is staff *m* & *n*.

Table 1. Differences in the observations of delivery personnel ($x_{t1:t2}$)

Difference / Staff(*t1*)	Maximum		Minimum	
	Staff(*t2*)	$X_{t1:t2}$	Staff (*t2*)	$X_{t1:t2}$
a	i	23.0	m, n	11.0
b	c, o	26.0	a	14.0
c	b	26.0	d	5.0
d	b	21.0	c, h	5.0
e	i	27.0	d	7.0
f	i	24.0	i	12.0
g	b	24.0	n	3.0
h	b	24.0	d	5.0
i	e	27.0	l	18.0
j	i	25.0	m, n	7.0
k	i	23.0	j	10.0
l	b	23.0	h	7.0
m	i	24.0	n	2.0
n	i	26.0	m	2.0
o	b	26.0	l	11.0

Table 2. Differences in the observations of all delivery personnel ($x_{t1:t2}$)

Staff / Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
a		14.0	16.0	13.0	16.0	17.0	12.0	14.0	23.0	12.0	14.0	15.0	11.0	11.0	20.0
b	14.0		26.0	21.0	20.0	23.0	24.0	24.0	21.0	22.0	22.0	23.0	21.0	23.0	26.0
c	16.0	26.0		5.0	10.0	17.0	8.0	6.0	25.0	12.0	14.0	9.0	7.0	7.0	12.0
d	13.0	21.0	5.0		7.0	14.0	7.0	5.0	20.0	11.0	13.0	8.0	8.0	8.0	13.0
e	16.0	20.0	10.0	7.0		17.0	12.0	10.0	27.0	16.0	14.0	13.0	13.0	13.0	16.0
f	17.0	23.0	17.0	14.0	17.0		15.0	15.0	24.0	17.0	19.0	12.0	14.0	16.0	19.0
g	12.0	24.0	8.0	7.0	12.0	15.0		8.0	23.0	8.0	12.0	9.0	5.0	3.0	16.0
h	14.0	24.0	6.0	5.0	10.0	15.0	8.0		21.0	8.0	12.0	7.0	7.0	9.0	14.0
i	23.0	21.0	25.0	20.0	27.0	24.0	23.0	21.0		25.0	23.0	18.0	24.0	26.0	19.0
j	12.0	22.0	12.0	11.0	16.0	17.0	8.0	8.0	25.0		10.0	13.0	7.0	7.0	18.0
k	14.0	22.0	14.0	13.0	14.0	19.0	12.0	12.0	23.0	10.0		17.0	11.0	11.0	18.0
l	15.0	23.0	9.0	8.0	13.0	12.0	9.0	7.0	18.0	13.0	17.0		8.0	10.0	11.0
m	11.0	21.0	7.0	8.0	13.0	14.0	5.0	7.0	24.0	7.0	11.0	8.0		2.0	15.0
n	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	11.0	10.0	2.0		17.0
o	20.0	26.0	12.0	13.0	16.0	19.0	16.0	14.0	19.0	18.0	18.0	11.0	15.0	17.0	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 3 and 4 shows the differences in skills of the total operation of delivery personnel and supervisors. Table 3 indicates staffs of maximum and minimum differences of each supervisor. Staff *b* and *i* are the staff of the maximum difference of each supervisor. Staff *g* and *n* are the staff of the minimum difference of each supervisor. A combination of staff and

supervisor of the largest difference is staff *b* & supervisor *ε* from Table 4. They has four skills of the large difference, *amount of load*, *classification of delivery routes*, *positon of package* and *the direction of the package when deliver to a customer*. A combination of staff and supervisor of the smallest difference is staff *n* & supervisor *Δ*.

Table 3. Differences in the observations of delivery personnel and supervisors ($x_{s:t}$)

Supervisor(s) \ Difference	Maximum		Minimum	
	Staff (*t*)	$X_{s:t}$	Staff (*t*)	$X_{s:t}$
α	*i*	27.0	*n*	3.0
B	*i*	29.5	*g, n*	13.5
γ	*i*	27.0	*g*	7.0
Δ	*i*	26.0	*n*	2.0
ε	*b*	30.5	*n*	12.5

Table 4. Differences in the observations of all delivery personnel and all supervisors ($x_{s:t}$)

Supervisor \ Staff	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
α	11.0	22.0	8.0	9.0	13.0	16.0	4.0	10.0	27.0	8.0	9.0	11.0	5.0	3.0	18.0
β	18.5	24.5	18.5	17.5	21.5	20.5	13.5	20.5	29.5	18.5	20.5	17.5	15.5	13.5	22.5
γ	13.0	24.0	12.0	11.0	17.0	19.0	7.0	14.0	27.0	17.0	17.0	15.0	13.0	11.0	15.0
Δ	11.0	23.0	7.0	8.0	13.0	16.0	3.0	9.0	26.0	7.0	9.0	10.0	4.0	2.0	17.0
ε	21.5	30.5	15.5	16.5	20.5	21.5	13.5	17.5	29.5	17.5	17.5	16.5	14.5	12.5	22.5

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

Table 5 and 6 shows the differences in skills of the total operation of supervisors. Table 5 indicates supervisors of maximum and minimum differences of each supervisors. Supervisor *β* and *ε* are the supervisor of the maximum difference of each supervisor. A combination of supervisors of the largest difference is supervisor *β* & *ε* from Table 6. They has two skills of the large difference, *original delivery routes* and c*lassification of delivery routes*. A combination of staffs of the smallest differences is supervisor *α* & Δ.

Table 5. Differences in the observations of supervisors ($x_{s1:s2}$)

Supervisor(s1) \ Difference	Maximum		Minimum	
	Supervisor(*s2*)	$X_{s1:s2}$	Supervisor(*s2*)	$X_{s1:s2}$
α	*β*	12.5	*Δ*	1.0
B	*ε*	13.0	*γ, Δ*	11.5
γ	*ε*	12.5	*α, Δ*	5.0
Δ	*β*	11.5	*A*	1.0
ε	*β*	13.0	*Δ*	10.5

Table 6. Differences in the observations of all supervisors ($x_{s1:s2}$)

Supervisor \ Supervisor	α	β	γ	Δ	ε
α		12.5	5.0	1.0	11.5
β	12.5		11.5	11.5	13.0
γ	5.0	11.5		5.0	12.5
Δ	1.0	11.5	5.0		10.5
ε	11.5	13.0	12.5	10.5	

Blue: From 1.0 to 10.9, Yellow: From 10.9 to 20.8, Red: From 20.8 to 30.7

6. Discussion

'Mizusumashi' aims to the just-in-time operation, only the necessary items in the necessary quantities at the necessary time (Ichikawa 2009). This paper considers that 48 skills of the home delivery are put for four ideal situations, necessary item, necessary quantities and necessary time and others in Table 7. Most skills are related to necessary time before arriving customer's home. Also, delivery staffs naturally needs to consider attributes of packages when preparing, loading and giving them. A dairy inspection and a manner at customer's home will be important for all three performances of just-in time operation.

Table 7. A relationship between ideal situation and skills in home-delivery operation

Ideal situation / Home-delivery operation	Necessary items	Necessary quantities	Necessary time	Others
I Decision and mapping of delivery routes	● Shape of package ● Attribute of customer	● A number of package	● A load per a day ● Estimated delivery time ● Designated date and time ● Designated address ● Classification of delivery routes ● Original delivery routes ● Closing da of customer ● Tendency of absence ● Customer's at-home time ● Delivery order	
II Efficient loading of deliverables onto a vehicle	● Size ● Wight ● Shape ● Alerting ● Damage of package	● Number of one customer	● Amount of load ● Positon of package ● In case of not loading planned all packages ● In case of being enough space in vehicle ● Change of weather ● Traffic rule	
III Focused driving			● State of road surface ● Utilization state of road ● Attention of walkers, bicycles and cars ● The way of stop ● The place where stop ● When bad weather	● Daily Inspection ● Roll-calling
IV Timely and hospitality deliver of the package to the customer	● Delivered package ● Safety delivery ● A check for going into customer's home ● A place to put a package ● Direction ● One voice ● Confirmation of delivery ● Sign of delivery	● Weigh		● Noise ● Neighbors ● Neighborhood ● A manner in customer's home

The result obtained from the analysis in the previous section shows that logistic capabilities of staff *b* and staff *i* are different from other staffs and supervisors. In the future problem of the academic side, a mathematical model for optimizing a combination for a pair-training and a pair-work will be designed. A dealing of the values of the two staffs are considered in the design.

7. Concluding remarks

This study suggests the essential skills for the proper operation with a tricycle, a typical small vehicle with a short turning radius like 'Mizusumashi' in Toyota Production System. As the result of an extraction of factors of the objective operation through several discussions between a home delivery expert and an academic researcher, 48 deduced factors are categorised under 4 main operations: I) decision and mapping of the delivery routes, II) efficient loading of deliverables onto a vehicle, III) focused driving, and IV) timely and hospitality delivery of the package to the customer. Moreover, a questionnaire is developed, incorporating the systematized factors. Subsequently, the relevant feedback of workers of case sites are investigated by the questionnaire, and the differences in the observations of the delivery personnel and supervisors are registered. Through the discussion based on the result of the questionnaire, the future direction of this study is considered compared with 'Mizusumashi' operation. These findings will be the basic data for the effective training and education of home delivery operations in the future.

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Linking government policy and supply network capabilities for design and transformation of supply chains - an investigation into interventions, configuration and influences

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Abstract

Globalisation of firms, disruptive business models and product complexities are driving the emergence of new production and service supply networks. These networks face continual reconfiguration due to the changing technologies, digitally driven business practices, global industrial shift and coalition dynamics. Such reconfigurations result in industrial policies being ineffective and misaligned to develop or sustain supply network capabilities. Government support mechanisms are becoming critical to strengthening industries in the present wave of economic crisis. This paper explores how the government policy interventions for industry are related to supply network capabilities. Concepts borrowed from policy and operations management fields are fed into developing an investigative framework for subsequent case analysis in government and industry. The study highlights the significance of influences in relation to network capabilities within a policy system. Results suggest that the interplays between policy interventions and the supply network configuration have profound implications to supply network design and transformation.

Introduction

The 2008 economic recession had a detrimental impact on many critical strategic business indicators including employment, profitability and customer demand. This crisis is affecting global business operations leading to instability and uncertainty. The cyclical recurrence of such global scale recessions is evident and confirmed by economic experts. Governments are compelled to extend support to businesses through policy interventions. Often the government policy agenda is informed by economic disciplines. Several experts identified the limit of economic based methods for an effective government policy (c.f. Chang, 2010; Rodrik, 2004), and preferred to provide an operational level context for government support mechanism. The area of the Supply Network is having implications for an industrial policy (Morash, 2001; Srai and Gregory, 2008; UNIDO, 2009), although not explicitly studied. A significant theoretical and practical gap exist in systematically linking supply network structure and dynamics with government policy development and interventions. This gap is observed in both Operations Management literature and Government Policy literature. The paper synthesises concepts mainly from two domains, Development Economics and Operations Management, and explores their linkages.

Globalisation of firms, disruptive business models, and product complexities, drive the emergence of new manufacturing supply networks. These networks face continual network re-configuration due to changing economic conditions affecting business models, international trade patterns and evolving national and international policy landscape. These complex dynamics renders in industrial policies misaligned with current needs of industry for growth. The relationship of the industrial supply network with the government policy system forms the central focus of this study. This paper explores how government industrial policies linked to the structure of supply networks impact network capabilities.

Theoretical Foundations

Manufacturing occupies the strategic position in multinational companies (Skinner, 1969, 1974). Manufacturing concepts are enriched by the thereotical prespectives involving a plant level (Hayes and Wheelright, 1984; de Meyer and Vereecke, 1994; Netland and Aspelund 2014), value chain (Porter, 1985), functional level (Ferdows, 1989, 1997), inter-firm network level (Cunningham, 1990; Lamming, 2000, Shi and Gregory, 1998), performance (Neely et al. 1995; Beamon, 1999; Neely, 1999) and International supply network level (Gnyawali and Madhavan, 2001; Koka et al., 2006; Srai and Gregory, 2008). Supply network configuration is linked to capabilities (Srai and Gregory, 2008). Through the configuration profiles, capabilities could be determined. The configuration determinant of a supply network is structure, flow, governance and value (Amini and Li, 2011; Caniato et al., 2013; Chandra and Grabis, 2007; Daley, 2009; Demeter et al., 2006; Dong and Xu, 2002; Lejeune and Yakova, 2005; Srai and Gregory, 2008; Truong and Azadivar, 2005; Willems, 1999; Zhang et al., 2008).

There is a limited literature specifying the impact of public policy on a firm level capabilities (c.f. Hans 1986), despite the government is often considered as one of the key dimension driving the global strategy of firms (Murtha and Lenway, 1994). The policy is also considered key agent to define 'value' in the value chain (Kogut, 1985; Kaplinsky, 2000). Economists usually link factor of productions (especially labour, and capital) to competitiveness. Resources and capabilities are differentiated owing to the ownership and specificity to a firm or network strategy (Barney, 2009). Resources are not firm specific. However, capabilities are the organisational capacity to deploy those resources to attain competitive advantage (Makadok, 2001; Sirmon 2007). Firm capabilities are linked to the supply network structure and dynamics (Srai and Gregory, 2008). Capability at a network level can be viewed as a bundle of resources and processes of an actor and can be used to study the performance of the network (Lavie, 2006).

The relationship between government policy and firm strategies have not received considerable focus in literature especially from a total supply network perspective. Morash and Lynch (2002) studied firm-level capabilities and linked those with a public policy from a demand-oriented performance perspective similar to Porter (1980). The linking of public policy with firm's supply chain performance is often applied in evaluating green agenda (Hall, 2005; Hervani, 2005), SME development (Boekholt, 1999), CSR (Maloni, 2006), etc. Most of the studies are focused on market-based perspective, even when it comes to contextualising public policy. In such studies, public policy is usually seen as 'resource complimentary' to a supply chain strategy. However, network capabilities such as internal processes improvement, efficiencies, and product service (PS) enhancement can be investigated in a policy system context that aims to enhance such capabilities. Therefore, focusing on an ‘industrial policy’ that targets network capabilities (efficiencies, connectivity and product/service enhancement, etc.) would be an appropriate prelude for investigating supply network configuration and its linkage with government policy system. The key capability clusters, used in this research are identified through the literature, these are:

- Supply Network Connectivity [SNC] (Bauer et al., 2001; Barratt, 2007)
- Total Network Efficiency [TNE] (Kavanagh, 2002)
- Supply Chain Process Improvement [SCPI] (Rich, 1997; Bititci 1997)
- Product and Service Enhancement [PSE] (Szakonyi, 1994)

The key theoretical dimensions of a policy system are policy institutions (Bennett and Howlett, 1992; Sabatier and Jenkins-Smith, 1993, Grindle, 2004; Cimoli, 2009), policy resources (Komiya, 1975; Cimoli et al. 2009; Di Maio, 2009; Pack and Saggi, 2006) and policy processes (Laswell, 1951; Sabatier, 1991; Baumgartner and Jones, 2002; Kingdon, 1995). Based on practice review of different countries manufacturing policies on the textile industry, key policy intervention categories were identified and refined through literature (given in Table *1*).

Table 1 - Policy Interventions

Policy Interventions Categories	**Evidence from Theory**	**Evidence from Practice**
Education, Information, and Awareness	Cimoli et al. (2009); Lall (1992)	• India • Bangladesh • Vietnam • Mexico • Germany • United Kingdom
Institutional Collaborations	Rodrik (2008); Keele (2007)	
Improving Productivity and Competitiveness	Kurgman (1994); Rodrik (2004); OECD (2010).	
Regulations, Deregulations and Liberalisation	Lall (2004); Gupta (1983); Gunningham et al. (1997); Lenox (2006)	
Natural Resource Exploitation	Hart (1995); Asiedu (2006)	
Technology Upgradation and Innovation	Branscomb (1995); Narula (2014)	
Establishing Macro-Economic Stability	Rodrik (2008); Suzigan (2006)	
Attracting Foreign Direct Investment	Branstetter (2006); UNCTAD (2011)	
International Trade Facilitation	Leonidou (1995); Bhagwati (1998)	
Infrastructure and Capacity Enhancement	Porter (1998); Rodrik (2008)	
Compliance and Sustainability	Hall (1993); Weiss (2000); Ahamed (2013)	
SME and Regional Development	Ceglie (1999); Irwin et al. (2010)	

Investigative framework development

The investigative framework involving key attributes, constructs, and investigative tools is developed and refined during the study. The final framework, resulting from practice review, literature, and cases, is given in Figure 1. The framework builds on the hierarchical structure of policy process. The first segment describes the logical flow from Vision development to

Operations with the principal factors covering different stages. Operations impact strategy which in turn influence policy and vision. This direction is often captured in Operations Management literature (Chandra and Grabis, 2007; Lambert and Cooper, 2000; Ostroff and Rosenbaum, 2007; Caniato et al., 2013; Srai and Gregory, 2008), but often limits to the extent of firm strategy. However, the current framework extends the scope of firm and network based influence to government policy development. Thirdly, actor influences exist within the system that accounts for the change in policy and network strategies, in a policy development context. These influences are captured in literature (Sabatier, 1993; Freeman, 1998; Morash, 2002; Pekkanen, 2014) and also through case studies (exploration and in-depth). These influences are bi-directional involving policy institutions and supply network actors. From case studies, it was evident that both government and industry can be reactive and proactive. Hence, the two influencing categories that came out from case studies were 'Government Reactive – Industry Proactive' and 'Government Proactive – Industry Proactive'.

The final framework combines Policy System and Supply Network System (structure and dynamics) and incorporates Configuration, Capabilities, and influences as shown in Figure 1 and provides following key information:

- Government Policy System and Policy Interventions.
- Supply Network Configuration and Supply Network Capabilities
- The implication of policy on supply network operations through hierarchical stages of Vision, Policy, strategy, and operations.
- Reactive and proactive influences exist within the policy system. These are either Government Reactive – Industry Proactive (GR-IP) or Government Proactive – Industry Reactive (GP-IR)

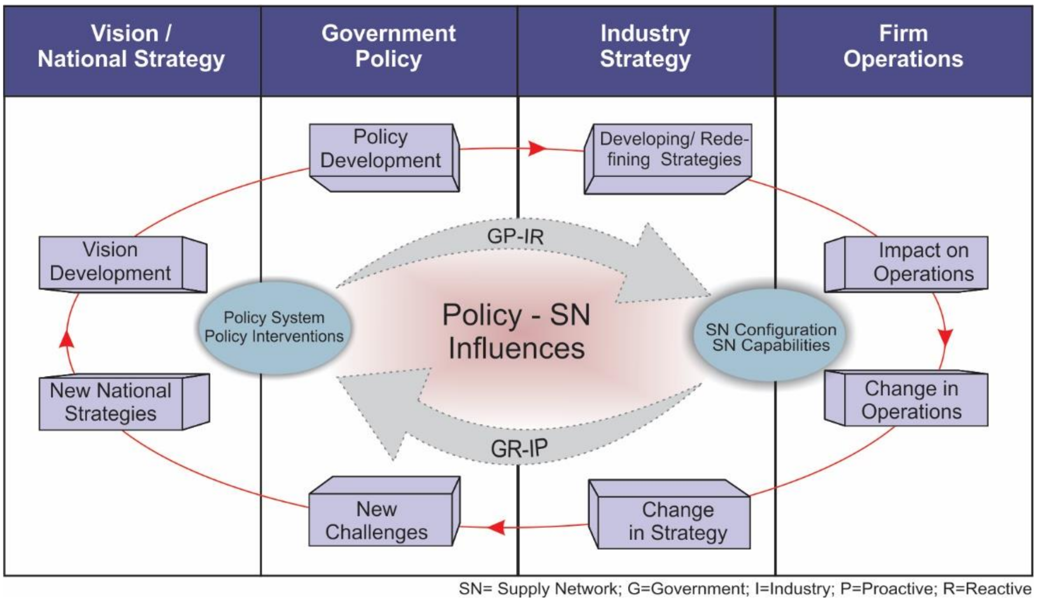

Figure 1- Investigative Framework

The framework guides practical complexity in industrial policy development and analysis in the context of supply network configuration and capabilities. Furthermore, policy influences, are also depicted in the framework that connects policy and supply network systems in both directions – reactive and proactive.

Case Investigations

In-depth investigations were conducted in Pakistan's textile industry. This was an exclusive case where the dimensions of enquiry, (both on policy system and supply network), are not captured by any existing frameworks. 'Influence mechanism' is defined as the unit of analysis of the research and applied to the policy system and the supply network. Insights gained through fieldwork, interacting with policy practitioners and direct observations of policy development processes were used in the investigation. The Both, Pakistan's first and second national textile policies were particularly investigated. Case interviews were held with CEOs of top textile firms and head of Business/Trade associations. A panel study was also conducted with leading policymakers at Cambridge to capture policy related challenges and processes. Case engagement and relevant information is summarised in Table 2.

Table 2: Industry Cases

Company	Type
A	Ginning company, BCI compliant
B	One of the largest synthetic fibre manufacturer in Pakistan
C	Among the largest textile composite groups
D	Among the top 3 largest composite groups in Pakistan
E	Among the top five largest textile groups in Pakistan
F	Oldest and among top five textile groups in Pakistan
G	Top garment manufacturer in Pakistan
H	The largest domestic market textile company to Pakistan
I	Largest garment company and supplier to UK/USA markets
J	Among the top five garment companies to serving UK/USA markets
K	Textile service providers and supplier, (machinery, consultancy, and chemicals)
L	Largest garment manufacturers association representing > 1000 companies
M	The largest textile association representing spinners and weavers. Representing about 400 companies
N	An association representing ginning industry

Result and Analysis

The linkage between Supply Network Configuration and Network Capabilities is also explored in the case study. Capability clusters are mapped at each structure node. This investigation provides a scope for establishing a further link with policy. Information relating to present the state and future plans gives an insight into capabilities type and categories.

In-depth case studies revealed that the analysis of an industrial policy system can give significant insight into interventions, actors coalitions and influences. On the other hand, Supply Network configuration investigation can enhance the understanding of network capabilities. The analysis is made between policy interventions and supply network capabilities. A summary is presented in Table 3.

Table 3: Policy Interventions, Network Structure and Capabilities

Policy Interventions Categories	SN Structure (.. at Nodes)	SN Capabilities Development Initiatives (Influences[1])	SN Capabilities Cluster	Evidence (Cases)
Education, Information, and Awareness	Fibre Development Ginning Non-Woven Garments	Up gradation of EDF institutes, NTU and TUP (IP)	PSE	A, G, L N
		Financial support in hiring of foreign teaching/research staff and foreign consultants (M)	TNE	C, D, G
		Publication of policy schemes and policy Information disseminations through workshops and seminars throughout the country. (GP)	SCPI	L. M. N
		Government consultations with industrial coalitions on zero rating of exports.	SNC	C, E, F, L, M, N,
Institutional Collaborations	Fibre Development MMF	Government -government institutional support for TUF Scheme (GP) and Market related interventions (IP).	SNC	L, M, N
		With Trade Assoc. such as APTMA and PSF for MMF (IP)	TNE	B, M
		Consultation with Associations and other coalitions for Tariff Rationalisation (IP)	TNE	B, L, M, N
	Fibres Ginning	Listing of High productivity spinning machines in TUF (IP)	TNE	B, C, D, E,
		Shifting from Power looms to Computerised Weaving machines (GP)	PSE	M

Policy Interventions Categories	SN Structure (.. at Nodes)	SN Capabilities Development Initiatives (Influences[1])	SN Capabilities Cluster	Evidence (Cases)
Improving Productivity and Competitiveness	MMF Spinning Weaving and Knitting	Servitization of Ginning (M)	SNC	A, N
Regulations, Deregulations and Liberalisation	Fibres Garments	Public-private partnership in infrastructure development of textile parks and cities (IP)	SNC	F.G.L.M
		To launch a comprehensive study to identify key regulatory bottlenecks facing industrial actors and devising mechanism to remove those (IP)	TNE	L, M, N
		Enforcement of Cotton Control Act Cotton Standardisation Ordinance for gaining maximum advantage of Pakistani cotton (GP)	PSE	A, M, N
		Zero rating of Exports (IP) – Drawback of Local taxes for Exports (IP)	SNC	L, M,
Natural Resource Exploitation	Fibres	The introduction of BT Cotton in South Punjab and Sindh Areas (GP).	PSE	A, M, N
		Encourage Organic Cotton Cultivation. (GP)	PSE	A, M, N
		Strengthening existing Cotton Grading system (M)	TNE	A, N
		Measures to encourage natural fibre diversifications (GP)	TNE	A,N,
Technology Upgradation and Innovation	Ginning Spinning Weaving and Knitting Processing	TUF Scheme to upgrade existing textile manufacturing technologies (GP)	TNE	A, D, F, H, L, M
		Establishing of e-commerce platform (GP)	SCPI	
		Upgradation of Ginning Technology (GP)	PSE	
		Conversion of Power-Looms to computerised weaving machines (GP)	PSE	
		RandD support to Universities and Research Centres in new product development (esp NTU) – (M)	PSE	
		Supporting Narrow-width processing and Knit Dyeing manufacturing (IP)	PSE	
Establishing Macro-Economic Stability	Fibres	Zero-Rating of exports (IP)	TNE	L, M
		Rationalisation of Tariff Structure (IP)	PSE	
		Export Refinance Scheme (IP)	SNC	
		Restructuring of Long Term Loans (IP)	TNE	
		Drawbacks of Local Taxes (IP)	TNE	
		Refund of RandD Support claims (IP)	PSE	
		Monetisation of PTA (IP)	PSE	
Attracting Foreign Direct Investment	Spinning Weaving and Knitting Processing Garments	Incentivising FDI in BT Cotton and Organic Cotton production (GP)	PSE	F, G, L
		Incentivising MandA (GP)	SNC	
		Incentivising JV in textile allied industries (GP)	SNC	
International Trade Facilitation	Garments	Initiation of Free Trade Agreement and Preferential Trade Agreements in key markets. (IP)	SNC	I, J, L
		Support for branding, grading and labelling of value added products (IP)	SNC	
		Reimbursement on local taxes for export products (IP)	TNE	
		RandD scheme on export (IP)	PSE	
		Marketing Insurance Scheme (GP)	SNC	
Infrastructure and Capacity Enhancement	Fibres MMF Spinning Weaving and Knitting Non-Woven Processing	Schemes for Warehousing, storage and marketing (IP)	SCPI	A, B, D, F, L, N
		Establishment of Textile and Garment Parks/Cities (IP)	SCPI	
		Establishment of Ginning Institute and Strengthening of Cotton Research Centre Multan (GP)	SCPI	
		Developing new EDF institutes (IP)	PSE	
Compliance and Sustainability	Fibres Processing	Subsidising costs of international social and environmental compliance certifications and audits for firms (IP)	SNC	D, F, G, L
SME and Regional Development	Ginning Filament Yarn Garments	Women Employment Support Programme – Picking up regulatory costs to companies for hiring female workers (GP)	SCPI	A, I, J, K, L
		Support for Disabled workers: EOBI and SESSI/PESSI to be picked up by government (GP)	SCPI	
		Establishment of research and development, testing and product development centre for carpet making (GP)	PSE	
		Incentivising Joint Ventures with International companies in textile allied industries machinery manufacturing, dyes/chemicals and accessories (IP)	SNC	

Industrial actors exhibit influences[1] on government policymaking to influence particular policy outcomes reflecting the network strategic objectives. It is observed that the type of

[1] Influences: GP=Government Proactive; IP=Industry Proactive; M=Managed

influences is directly related to capabilities and the nature of coalitions existing in supply network actors. Supply network capabilities are compared with Policy Interventions, shown in Table 4.

Table 4: Policy Intervention Categories and Supply Network Capabilities

Policy Intervention Categories	**Supply Network Capabilities**			
	Product Service Enhancement	**Supply Chain Process Improvement**	**Supply Network Connectivity**	**Total Network Efficiency**
Education, Information and Awareness	X	X	X	X
Institutional Collaborations			X	XX
Improving Productivity and Competitiveness	X		X	X
Regulations, Deregulations and Liberalisation	X		XX	X
Natural Resource Exploitation	XX			XX
Technology Upgradation and Innovation	XXX ★	X		X
Establishing Macro-Economic Stability	XXX ★		X	XXX ★
Attracting Foreign Direct Investment	X		XX	
International Trade Facilitation	X		XXX ★	X
Infrastructure and Capacity Enhancement	X	XXXXX ★		
Compliance and Sustainability			X	
SME and Regional Development	X	XX	X	

X: SN Capability Development Initiatives

★ Significant Capability Development Region

Discussion

The Supply Network Capability cluster that is more related to Proactive Government Influence is Product Service Enhancement. The information reveals that that the network actors and coalitions are not significantly responsive to new Product and Service Enhancement, including R&D Efficiencies and New Product Development. From supply network perspective, it is insightful to understand how Macro-Economic levers impact product and services. The capabilities development actions under the intervention category of Establishing Macro-Economic Stability mostly relates to providing fiscal support and tariff protection to firms. Perhaps, these measures enhance liquidity, which allows firms to further improve their product and services.

It is also observed that Government proactively supports Supply Chain Process Improvement while supply network actors are rather reactive to such policy influence. However, the most significant interventions under Supply Chain Process Improvement are under the category of Infrastructure and Capacity Enhancement, which is rather of an industry proactive nature. Infrastructure projects such as Textile City in Karachi and Garment Manufacturing Cities in Faisalabad and Karachi significantly enhance manufacturing, logistic processes and enable firms to achieve economies of scale. It is interesting to observe that establishing e-commerce platform is a government-driven agenda in case of Pakistan.

Both capabilities clusters relating to Supply Network Connectivity and Total Network Efficiency exhibit Industry Proactive influence. However, many initiatives under Network Efficiency are 'Managed'. The significant intervention category relating to capability cluster of Supply Network Connectivity is the International Trade Facilitation. The key Capability development factor involves the initiation of free trade agreement or preferential trade agreement with other countries, supporting technology spill-over through incentivising MandA, financing exports on easy terms, etc. Total Network Efficiency capability significantly relates to the intervention category of Establishing Macro-Economic Stability. Other key interventions involved in this capability include Natural Resource Exploitation and Institutional Collaborations. Analysing this particular case of Total Network Efficiency, it was evident through the case study that firms adopt supply-side measures (raw material and technology), demand side measures (export financing and tariff rationalisation) and operational efficiencies (engaging consultant), to enhance product quality and lean process implementations. Supply-side measures are Government Proactive influenced.

Overall, it is observed that industry exhibit reactive policy influence to those capabilities which are related to functional level performances, while the government influences proactively in this case. This is perhaps due to the fact that firms hesitate to seek direct government support where there is a significant confidentiality in its internal operations are concerns. This confirms the case study evidence where such hesitations and concerns were highlighted.

The relationship between policy interventions and supply network capabilities have profound implications on supply network design capability and overall policy system competence.
Following are the key findings from the analysis:

- The investigation into capability clusters for a particular supply network node gives an insight into policy requirement for that particular network node.

- The upstream supply network actors tend to have more Supply Network Connectivity agenda.
- Coalition formation within the supply network is more significantly related to supply network structural similarities rather than common network capabilities.
- Network Capabilities are significantly linked to actor and coalition influences within a policy environment.
- The relationship between policy interventions and supply network capabilities have profound implications on Supply Network Strategic Design and overall Policy System competence.
- Government industrial policy system competence is significantly related to the total supply network capabilities.

Conclusions

This study draws on the literature of development studies and considers resources, institutions, and policy processes as key policy system dimensions. Similarly, supply network structure, flow, relationship and value from the Operations Management field is used to build an investigative framework for subsequent case study analysis. A case study approach is used in this study to develop a framework to inform OM theory. The study was performed in the textile industry due to its dynamic international supply chain with significant social, economic and environmental implications, particularly in developing countries, requiring critical government policy considerations. Initial exploration is done in different countries to identify and categorise of Policy Interventions and Supply Network Capabilities. In-depth case studies were then carried out in Pakistan, selected as a country, where textile is the most significant sector of its economy, and it is ranked amongst top textile producing and exporting country in different the product categories.

Results suggest that supply network configuration has a significant impact on government policy decisions that is neither explicit nor well understood. It concludes that firm capability is directly linked to supply network configuration and particular coalitions within a given configuration, significantly influence the policy system. These influences between industrial actors and institutional players are bi-directional in nature illustrated in the policy system as proactive and reactive approaches. Furthermore, policy interventions directly support supply network capabilities by facilitating coalition formation. The investigation into capabilities for a particular supply network node gives an insight into policy requirements. Understanding actor influences in the context of a supply chain transformation is can lead to an appropriate network design to build or sustain network capabilities. The role of government in ensuring the availability of funding, infrastructure, standards, market access to new product and technologies is critical to a global network design. Policy interventions and industrial strategies provides essential information, and in most of the cases, appropriate resources for supply chain transformations.

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Mastering the digital transformation requires excellence in fundamentals: Partial effectiveness in supply chain design can be expensive

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Abstract

Redesigning and digitizing supply chains provides a number of advantages, including increased collaboration and problem solving effectiveness, and faster product introductions. They also can induce reductions in response times, lead times, and time to react to customer issues. But even with advanced integration of digital technologies and the establishment of co-located teams to more effectively execute a digital supply chain strategy, some strategies may be only partially executed due to incomplete analysis and inadequate assumptions, resulting in partial effectiveness of the strategy.

In this study, we use a global computer manufacturer and a key server product line as a case study, and evaluate the cost of inefficiencies in their strategy. Due to nonrandom demand patterns, the company accepted a structural demand patter rather than smoothing demand due to customer power and preferences. Our analysis suggests these inefficiencies between the OEM and a key supplier increase costs almost three-fold over those estimated by the company, resulting in excess costs in the tens of millions of dollars for one product line alone. We conclude the study by presenting an optimal solution for both the OEM and supply to reduce these expensive inefficiencies to near zero.

How is Big Data Transforming Operations Models in the Automotive Industry: A Preliminary Investigation

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***Abstract* - Over the years, traditional car makers have evolved into efficient systems integrators dominating the industry through their size and power. However, with the rise of big data technology the operational landscape is rapidly changing with the emergence of the "connected" car. This is a type of autonomous vehicle which utilizes smart city technology. The focus of this paper is with exploring the potential for future electric and shared mobility services within the smart city. This work forms part of an on-going research study exploring the proposition that big data is a resource that can be utilized to build service capabilities. Furthermore, through big data resources, shared capacity and improved car mobility services can be achieved within the smart city. The automotive incumbents will have to harness the opportunities of big data, if they are to remain competitive and deal with the threats posed by the rise of new connected entrants (i.e., Tesla). These new entrants unlike the incumbents have configured their operational capabilities to fully exploit big data and service delivery rather than production efficiency. They are creating experience, infotainment and customized dimensions of strategic advantage. Therefore the purpose of this paper is to explore how "Big Data" will inform the shape and configuration of future operations models and connected car services in the automotive sector. It uses a secondary case study research design. The cases are used to explore the characteristics of the resources and processes used in three big data operations models based on a connected car framework.**

Keywords - big data; automotive industry; business model; operations model; connective capability

I. INTRODUCTION

As today's consumers are surrounded by connected devices, such as smartphones and tablets, the idea of connected cars is gaining in popularity. It is estimated that by 2025, all new passenger vehicles will be connected [2][4]. Yet, the connected car represents a major disruption to the automotive industry's traditional value creation model. A connected car can be defined as: "*a car that is equipped with Internet access, and usually also with a wireless local area network. This allows the car to share internet access with other devices both inside as well as outside the vehicle*"[1]. These services are made possible by a firm's capacity to capture and leverage high volumes of structurally diverse and high-speed data ("*big data*") generated by the sensors and embedded electronics of connected devices.

Two main service segments can be clearly distinguished in the growing connected car market: i. integrated product-services (to enhance the driver experience) and; ii. mobility services (to offer alternative modes of transportation from traditional private car ownership). Furthermore, moving into the service economy opens new streams of revenue for traditional manufacturers [6] and big data will enable superior value creation based on closer customer intimacy. However, it also opens up the automotive industry to competitors from outside their traditional industry channel who are more proficient than incumbents at leveraging big data. In an industry unchanged in decades, these new entrants are finding ways to innovate and meet diverse customer needs for more information and mobility services, configuring their business and operating models around big data.

This work will help to identify from an operations perspective how big data is re-shaping the provision of products and services in the automotive industry, as it evolves towards further connectivity and autonomous driving. Whilst different models continue to co-exist, it is important for incumbents to understand how emerging operations models are configured compared to traditional models so that they can be proactive rather than reactive to the big data-driven disruption of the automotive industry.

Big data is commonly hailed as the next frontier for productivity, innovation and competition [3]. As a complex and multi-faceted concept, it impacts on many things in different ways. Therefore, to narrow the scope of the study, big data is considered in terms of how it impacts on the way in which resources and processes are managed within an operation. This is justified because the way in which resources and processes in an operation are managed has a strategic impact on the organization [3]. It is therefore valuable to look at the configuration of emerging operations models to explore the impact of big data.

As operations models are dynamic and fast-changing, the overall objective is to identify the characteristics of the emerging big data-enabled operations models in the automotive industry. To our knowledge, this topic has not yet been theoretically studied from an operations perspective and there is a need for work to fill this research gap. A conceptual framework of an emerging big data-connected operations for the automotive industry is developed, based on the literature, and the underpinning concepts are examined through theory-guided case study analysis.

The structure of the paper is as follows. Section 2 presents the theoretical framework which will be advanced by our case study investigation. Section 3 details the research method. Section 4, presents the initial results of our on-going case study investigation. Finally, in Section 5 we summarize the key conclusions and implications for future research as we seek to build our investigation.

II. Theoretical Framework

While moving to a consumer-centric service approach based on big data has economic benefits, there are operations challenges. The main challenge for incumbents is a shift in the nature of value. Operations models must be able to process information and customers more than raw materials. The basis for all connected car services is information. With customer value based on intangible services, each stage of the transformation process is different; resource inputs and process outputs have perishable value if not captured and consumed in time. The transformation process is shaped by new constraints, including a company's capacity to capture, analyze and leverage real-time big data in the operations model [7]. The characteristics of the operation's resources, processes and capabilities are described in Fig. 1. The dotted line illustrates the scope of analysis in the case studies. In contrast to traditional operations models that predominantly process materials, emerging operations models in the automotive industry process information (big data) and customers. It is therefore proposed that big data and customers are the dominant transformed resources, while the dominant transforming resources comprise big data analytics (to extract insights from the real-time data captured) and vehicles (to physically transport the customers).

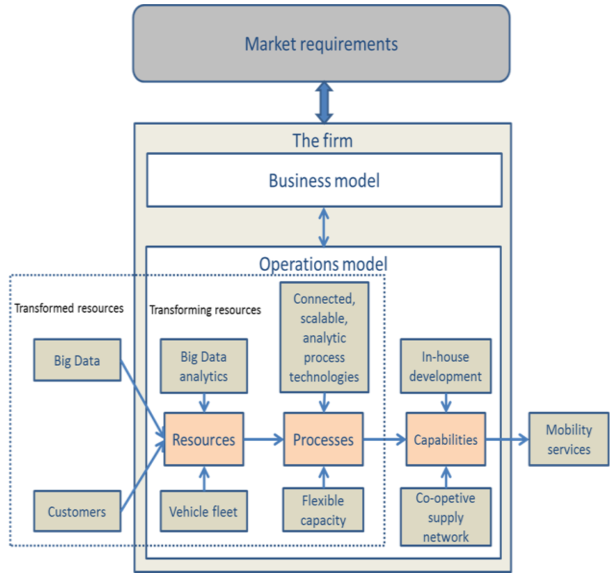

Figure 1. Emerging big data-connected car framework

III. Research Method

A multiple case study design was chosen to strengthen conclusions drawn from the cases and to increase external validity [8]. Three secondary cases were purposefully chosen according to the logic of theoretical sampling. That is, cases were selected based on the likelihood that they would critically challenge the predicted theoretical findings. This helps to confirm or advance the theoretical model. All the case studies were chosen according to their varying degrees of reliance on big data. As such, big data is the primary input into the operations model. That is, all services in the cases delivered to customers rely on real-time information extracted from big data. The first two cases Uber and Drive Now provide ride-hailing and car sharing services; the third case Tesla offers over-the-air software updates for its customers and customized services from: product design, through to purchase, product performance monitoring and after sales support. As their products diverge from the traditional offerings of the automotive industry, their operations models constitute "emerging" operations models.

IV. Findings

Uber and DriveNow are examples of pure mobility services, Tesla is an example of a company using big data to deliver services related to its manufactured product, namely the owned electric vehicle. Despite these differences, several trends emerged across the three case studies. The operations outputs vary across the case studies. However, when compared to traditional operations models delivering a focused product, these emerging operations models have been designed to deliver a multi-variant consumer experience. For example, the operations outputs for Uber and DriveNow are to meet an immediate and real-time demand for flexible transport in urban environments.

In the case of Tesla, the service operations output is multi-faceted because Tesla provides a service offering based on a product, namely the vehicle that is sold to a customer. Tesla's service uses big data to understand, maintain and also improve vehicle functionality in line with customer expectations. It maintains vehicle functionality by collecting diagnostic data on individual vehicles, and improves vehicle functionality by aggregating driving data to understand driving conditions and vehicle performance, optimal locations are for charging stations. In terms of outputs that are software-based, such as those mentioned in the case studies, they are not constrained by time and space in the same way as tangible outputs. Updates to the service can easily be applied without physical presence or a mutually agreed time. One particularly noticeable trend across all case studies is therefore that of producing minimum viable products. This means that instead of delivering perfected products and services to customers, the company determines what is the minimum viable level for the service to work, produces that and then tweaks and perfects it based on how it is used and perceived by customers. It illustrates the importance of on-going relationships with customers, rather than ending the interaction at the point of sale.

The concept of allowing customers to use unfinished products is novel in the automotive industry. With feedback loops and real-time monitoring enabled by big data, the customer becomes part of the operations improvement process. It enables companies eventually to deliver exactly what the customers want. Tesla is a key example of this. Its major software updates (new, improved features) are released on a yearly basis, while minor updates (bug fixes) are released on average every month.

The hardware suite required for semi-autonomous driving (named "Autopilot") has been fitted into Tesla's vehicles since 2014. It includes forward-facing camera and radar, 12 long-range 360-degree ultrasonic sensors, global positioning systems (GPS) and electric braking system. Whenever vehicles are in manual mode, Tesla crowd-sources the fleet's driving data. Using so-called "fleet learning technology", Tesla uses these datasets to train its driving algorithms which ultimately are what drives the car when in Autopilot. The first version of Autopilot was released by over-the-air (OTA) software update in 2015, and is still in beta mode today. This means that it is the driver's responsibility to remain alert at all times. While Autopilot is engaged, signals are sent back to the Tesla headquarters (HQ) server whenever a driver intervenes (i.e., by adjusting the steering wheel or braking) or resumes control. Based on these aggregated driving datasets, Tesla identifies where problem areas are and is able to investigate and improve the software. As the fleet learns, improvements can be noticed in days.

Uber is another example of a company producing minimum viable products. Its underlying system architecture was developed by many teams in any way possible as it rapidly expanded in the first five years. The result was a mixture of architectures. Therefore, a new system architecture was developed in order to support new customer preference services. DriveNow was established as a separate entity from its parents company Bayerische Motoren Werke AG (BMW) to benefit from the agility of a start-up. It encourages customer feedback and adapts its operations model to suit.

Across all case studies, customers are the predominant transformed resource. This is in contrast to traditional operations models which focus on transforming materials into a product. Moreover, all services delivered to customers in these emerging operations models rely on real-time information extracted from big data. Although there are differences between the models as to what information is collected and analyzed, GPS positioning is captured in all models. Not only does this help riders and drivers locate each other / a suitable vehicle, but the GPS data generated from usage also helps companies to understand customers' popular routes and improve service provision.

While in traditional operations models, big data is used to enhance visibility over existing processes, in emerging operations models big data is one of the primary inputs enabling the provision of the service. Because of this the service operations of the case studies rely more heavily on intangible inputs, namely information. The value of such information is specific to time and space and if it is not captured, it is lost.

In every case, the operations model is configured to provide a flexible and convenient service. Inherent in the provision of services is fluctuating demand [5]. With big data, the companies in the case studies are able to monitor supply and demand in real-time and even to identify challenges ahead of time. They configure their capacity to accommodate a certain level of demand fluctuation, but importantly they also directly manage capacity by influencing the levels of supply and/or demand. The intangibility of services means that they cannot be easily stored [5] and therefore customers are less likely to be willing to wait for services than they are for a finished product.

For Uber, flexible capacity is achieved by not employing its drivers or owning a fleet of vehicles. Demand and supply are managed by surge pricing. For DriveNow, service capacity is constrained by the size and functionality of the fleet; if customers do not find a car available in a suitably close location, the service is of no value. Flexible service provision is therefore enabled by deploying a large fleet and a small team of service agents who check tyre pressures, clean the cars and move them to more popular locations if necessary.

Supply and demand are managed through incentives for customers to park in optimal locations and fixed pricing. For Tesla's service delivery, flexible capacity is configured by designing the vehicle from the ground up to ensure that features can be updated safely via software updates over time. However, Tesla also has to manage the constraints of producing hard products vehicles and is constrained in the usual way for the manufacturing side of its product-service.

Tesla vehicles contain over 3,000 purchased parts sourced globally from over 350 suppliers. Tesla's supply chain is a "unique hybrid of the traditional automotive and high tech industries" which means its pace is faster than traditional automotive supply chains. If suppliers cannot keep pace, software development and manufacturing is brought in-house.

While other automakers plan their production layout to keep it the same for several years to minimize costs, Tesla's production engineers move machines around frequently as a learning exercise. The company uses Tableau visualization software to monitor its production lines minute-by-minute. In terms of its supercharger network capacity, Tesla decides where to locate capacity by collecting and analyzing driving data from its fleet. It takes into account route patterns and local driving conditions. Each supercharger station is itself connected to the Tesla network, both for monitoring and maintenance purposes, but also to let customers know availability via Tesla's vehicle Navigation system.

By design, all the case studies have a reliance on connectivity. Without connectivity in the process technologies, the big data cannot be created and captured. Tesla has the most advanced configuration for connectivity as its vehicles have been designed from the ground up for connectivity. This enables OTA software updates for all functional features of the car. The hard asset requirements of the vehicle and the production efficiencies mastered by incumbents mean that few new entrants could offer a viable competitive threat to incumbent automakers in the traditional arena.

However, in the new market, new entrants are using big data to innovate entirely new operations models to deliver new products and services based on a closer understanding of customer's on-going needs. They are defining the strategic agenda for capturing, analyzing and leveraging big data in their operations models. Free from the organizational structures and investor commitments of the traditional players, the new players are better able to address fluctuating demand in the service area.

V. Conclusion and future research

This paper is an initial attempt to make a scientific contribution to operations management theory in big data contexts. The focus of our work is on trying to find an answer to a central research question of: how big data is transforming organizations at a process level? Furthermore, that big data is a resource that can be used to build service capabilities. We aim here at setting out a new research agenda that fuses and crosses the boundaries of operations management and big data technology. As the prominence of big data continues to develop and stakeholder groups become increasingly knowledgeable and engaged, there is considerable incentive for operations managers across industry sectors to consider the opportunities and challenges facing their processes and people, as well as the tools and frameworks they deploy for strategic and operational decision making.

The opportunities are not only in improving efficiency and effectiveness of their existing operations, but also in transforming their operations models, and in some cases, developing radically different new ones. They must become more customer-centric and service driven in this big data age. The automotive industry has evolved from Ford, to the TPS and post-Fordism, but now in the second decade of the twenty first century it is information and service not production driving the operations model. This is information driven automotive sector characterized by low inventory, customization, dissolvable supply chains, leasing, joint automotive/information and communication technologies (ICT) ventures, Silicon Valley driven product R and D, the delivery of shared services and pooled capacity.

For organizations developing new operations models, the challenge is to build on and leverage the new digitized infrastructures emerging with smart and intelligent cities, in order to connect physical goods, services, and people (offline), with real-time data driven processes (online), in seamless online-to-online (O2O) operations. This requires a re-design of long run operational competencies and capabilities in order to respond to the rapidly changing city environments.

Despite the importance of operations management to big data implementation for both practitioners and researchers, we have yet to see a systematic framework for analyzing and cataloguing emerging operations models. As such, our conceptual framework makes an initial contribution to operations management theory in the big data context. This research only used three 'theory-guided' cases studies to illustrate the big data transformation of operations models. Therefore, much more in-depth analysis and more detailed models are clearly needed to assist in the implementation of big data initiatives and facilitate new innovations in operation management. Some of the changes that operations and their connected supply chains face are revolutionary, and this requires careful consideration from both a practical and theoretical point of view.

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A decision support model for the market development process for emerging markets in the automotive industry

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Abstract. The sales potentials for automotive companies in the core markets are decreasing and emerging markets, such as the BRIC-states or the ASEAN countries, are now in the focus of European automobile manufacturer's attention. However, the OEMs have to face different challenges in the market development process of these high potential markets. The high number of legal requirements both for the import of fully build up cars and the local production with globally sourced parts results in a very time consuming decision finding process which makes fast adjustments of the business model in case of a changing business environment nearly impossible. Therefore, this paper proposes an approach to support the decision finding process by identifying the influencing variables and developing a model for optimizing the OEM network configuration that enables demand fulfillment in all markets at minimal costs for automotive emerging market businesses.

Keywords: Market Development, Decision Support, Supply Chain Management, Automotive Industry

1 Introduction

The traditional automotive markets in Europe, the USA and Japan are decreasing, but on the other hand the globalization process offers new sales opportunities, especially in emerging markets like the BRIC states or the ASEAN countries (KPMG 2009). However, the access to those markets is often restricted by tariff and non-tariff trade barriers in order to protect the local economies and promote local value creation both at production and supplier sites. The European OEMs have to decide whether to enter those markets and which market development strategy fits best in the sense of production and supply cost and performance measures. The high number of legal requirements both for the import of fully build up cars and the local production with globally sourced parts results in a very time consuming decision finding process.

Today available decision support models and methods include production and logistics costs as well as customs barriers, but other trade barriers are not part of those models (Ferber 2005; Meyer 2006; Schmaußer 2011). The consequence is that actual decision support models are not complete and have to be supported by qualitative and value benefit analysis to include all necessary impacts. This leads to qualitative and often subjective results, which have to be evaluated in time-consuming collaborative processes.

The present paper introduces a new approach which includes non-tariff trade barriers into a mathematical decision support model and enables a holistic analysis of development strategies for emerging markets. Therefore, the paper identifies the most important variables influencing the decision finding process and transfers them into a mathematical description taking the analyzed dependencies and restrictions into account. The result allows the assessment of different business cases and proves the significant influence of those non-tariff trade barriers on such a decision making process.

2 Derivation of variables triggering complexity in global automotive production

Decision finding in market development questions is a very complex task due to multiple possible forms of network configuration. From an OEM perspective existing production network structures should be considered when calculating business cases for market developments. Therefore, the assessment of possible network configurations is needed. An identification of variables and the ability to allocate related costs and quantitative measures is needed to model and compare business cases based on various network configuration scenarios. In the following an automotive production network is specified as a complex system. To provide OEMs with a new approach to handle complexity in the evaluation process of possible network configurations an identification of relevant network variables has been performed in chapter 2. Therefore, an analysis of general structures and processes within global automotive production, sourcing, logistics and international trade barriers was conducted.

2.1 Analysis of general structures and processes in international automotive production networks

Global Automotive Production

Automotive business functions like research and development, sourcing, production, distribution and aftersales can be dispersed globally at different business locations and conducted by various business partners. Global automotive production today is therefore organized in production networks. A production network consists of one or more companies that are connected by supply relations (Meyer 2006). From a supply chain perspective, the OEM builds the center of the chain. The value chain converges over multiple supplier tiers until production at the OEM and diverges at the distribution across retailers and end customers. Production at the OEM integrates multiple production sites (Wittek 2012). Production plants distinguish in production abilities and equipment attributes. According to the performed business and production functions network locations can obtain certain roles. So called *server factories* provide specific regional markets and are able to evade customs and tariffs regulations. *Offshore factories* use low cost production strategies to produce specific parts at minimum expenses and distribute these parts via export to demanding network locations. Another example are *lead factories* which develop new processes, products and technologies to spread and transform them within the network (Friedli, Schuh 2012). A significant impact triggering complexity in automotive production is the rising variety in products and variants (Ebel et al. 2014). Furthermore, model selection for specific markets as well as variant adaptation for local demands need to be met in the context of network configuration. Production sites within the network differ in capacities and production output volume due to the layout of the production site and the specific production lines. These features need to be considered for vehicle production allocation, when designing production strategies. Production strategies determine the selection of vehicle models, including decisions about platform strategies, production line design and used production equipment. The depths of production, meaning the design of production steps along the production line, including pressing plant, body construction, painting and assembly can also be regarded as a feature of a production plant. Not every local production site provides each function. It can be distinguished between production sites offering all production functions and assembly plants only. For example, in the context of serving developing markets, some production sites (e.g. server factories) simply offer assembly functions. Therefore, production and supply strategies need to consider that specific production sites need to be supplied with specific pre-assembled parts and components (e.g. completely and semi knock-down strategies) (Klug 2010). Exact plans of the local production process and buildability checks are needed. Another factor influencing local production site layout as well as agreements with contracting partners is the strategy of internationalization. It can be distinguished between following forms of market entry: export, contract manufacturing, licensing, minority participations, strategic alliances, joint ventures, subsidiary's and mergers. Some partnerships require high investments costs in the foreign market, which need to be considered at network configuration tasks (Schmid, Grosche 2008). Country specific legal and political norms influence strategy selection for market entry respectively for corporation with local production partners. They also effect local content requirements and regulations concerning local value creation. These requirements need to be obtained when creating network configuration because they determine specific parts and components for local production (Köhne 2013). Local content requirements also need to be recognized in the sourcing process and the bill of materials in order to deliver the correct amount of parts and components. Other substantial factors are local political, legal, economic, social, technical and environmental situations. Knowledge about international business environment and general market conditions can lead to competitive advantages for OEMs. The competitiveness of production locations is influenced by different levels of factor and overhead costs and quality and efficiency of partners and service providers. Topographical characteristics, available structures for transportation, information and communication also affect network configuration decisions. (Göpfert, Braun).

Global Automotive Sourcing

Sourcing strategies imply from which supplier parts and components are delivered to the production sites of the OEM (Klug 2010). In general sourcing strategies of demanding parties pursue maximum benefits at minimum costs (Gudehus 2012). OEMs have set standards of quality requirements and seek suppliers that deliver parts and components at the lowest price. In international automotive networks, materials are sourced in different states of assembly. Sourcing strategies can include the sourcing of single parts and components, the sourcing of pre-assembled modules (*system sourcing)* (Werner 2013), the sourcing of pre-assembled vehicles due to country specific import regulations and production line design in local assembling plants (knock down strategies) and the ordering of completely assembled vehicles for sales activities in target markets (*completely build up vehicles)* (Klug 2010; Köhne 2013). Common sourcing strategies can be divided into local, regional and global sourcing. In the context of international automotive production local sourcing strategies are to be applied, when country specific local content regulations exist. Finding local suppliers that meet the OEMs quality requirements can lead to additional costs for supplier development. In emerging markets local supply is generally backed up by regional or global suppliers. That leads to the concepts of single sourcing (parts and components are delivered by one supplier only), dual sourcing (parts and components are delivered by two suppliers to secure supply in case of delivery failure) and multiple sourcing (more than two suppliers for certain types of parts and components) (Klug 2010).

Global Automotive Logistics

Supply chain management and logistical structures support the international production network. Referring to the definition of a supply chain from CHOPRA and MEINDL a supply chain consists of all parties participating in the fulfillment of a customer's request. For that reason, a supply chain integrates manufactures, suppliers, transporters, warehouses, retailers and customers (Chopra, Meindl 2014). In the context of this paper, transportation of parts, components and pre-assembled vehicles (knock down strategies) from suppliers to production sites (local and international) are to be considered as well as transportation of completely assembled cars from production sites to target markets. International transportation networks consist of knots and edges in theory. Edges are transport routes of a certain direction and lengths. When designing transportation routes *modal choice,* which refers to the choice of a certain mode of transportation, including road, air, sea, and rail is to be considered. The choice of a transportation mode determines delivery costs and time. It also includes the choice of a logistics service provider, who offers logistics services (e.g. shipping and handling) in a certain depth and quality and uses freight rates, which vary according to demand development.

Besides the locations of suppliers, warehouses, production sites and retailers, the choice of the transportation mode leads to the specific location of knots in the network. Knots (transshipment and consolidation points) connect multiple edges within the network (Schieck 2008). Typical functions in transshipment points can also be warehousing and packaging activities to meet the requirements of material security and timing strategies within logistical concepts. They have an effect on costs and efficiency of supply structures. Depending on the properties of material (e.g. dangerous goods, stage of preassembled components) special packaging requirements, as climate adjusted packaging, occur (Göpfert, Braun). In the context of this paper, a general international transportation route can be subdivided in pre-carriage (transportation from supplier to consolidation hub or border of departure country), main carriage (transportation from hub or border of departure country to hub or border of receiving country) and on-carriage (from hub or border of receiving country to production site). These *multistage supply chains* cause higher risk in reliability of supply set off by numerous supply chain interfaces and lead to higher uncertainty within the system (Klug 2010). The decision of production programs should consider delivery capability of suppliers as well as appropriate capacities for processing production material throughout the chain of freight forwarders, packaging sites and transshipment points as well occurring costs for additional capacity acquisitions. The number and diversity of network integrated customs offices rises with increasing internationalization as well as the complexity in process management, document management and management of information and financial flows (Göpfert, Braun).

International Trade Barriers

When designing global production and supply structures with border-crossing material transportation, trade barriers are an inevitable parameter. Trade barriers can be a dynamic factor due to changes in government and economic development (Göpfert, Braun). Trade barriers can generally be categorized in tariff and non-tariff trade barriers. Tariff trade barriers summarize duties and levies for imported and exported goods. Within global automotive supply structures tariff trade barriers work as financial devices, restricting import amounts of products. Governments raise import duties to protect domestic markets. Diversity of duties for different stages of preassembled components can lead to a shift in value creation in domestic economies. For internationally shipped parts and components certain customs rates apply on the parts price and partially on the shipping costs. Customs rate vary strongly regarding the import of parts and components and completely assembled cars. Non-tariff trade barriers including quotas, limitations and administrative trade barriers according to SIVAKUMARAN ET AL. can restrict amounts and values of parts and components imported into a target market. An important example affecting automotive production are quotas for local content targets. If certain local content specifications are prescribed parts and components need to be sourced locally. Therefore, supplier development costs may occur (Sivakumaran et al. 2015).

The above analyzed structures and processes of global automotive production do not intent to be a complete of automotive production, but represent main features that when determining scenarios of network configuration. Features of network configuration are interconnected in various relations. A change in one variable may have an effect on many other elements and relations within the system. The next chapter describes the complexity of the automotive production system.

2.2 Complexity within international automotive production

Adhering to LUHMANNs definition complexity of the whole automotive production system can be described as follows: A characteristic of a complex system is the amount and diversity of possible relations within a system (Luhmann 2005). In the system of international automotive production, relations between OEMs and suppliers, customers, production corporations, logistics service providers and customs offices were identified amongst others. Also objectively determinable system properties could be identified, e.g. available production capacities, design of production lines, locations of suppliers and consolidation points, available modes of transportation and transport distances, costs for customs and tariffs as well as regulations for local content and local value added. Another characteristic of complex systems is the lack of transparency, e.g. due to decentralized production, globally distributed suppliers and multiple stage supply chains. Many partners are involved in the automotive production process and needed information are not at any times available for every partner in the network. Because of multiple parties involved in international automotive production there is a diversity in system interfaces, due to partners being equipped differently in systems and technology. A rising diversity in vehicle models and variants is driven by more individualized customer demands and adapted variants for local markets. High dynamics, situation-specificity and a certain degree of uncertainty in overall conditions in international automotive production is triggered by variations in vehicle demand, the need for new supply concepts when entering new markets due to diverse trade barriers, and supplier development costs (Bretzke 2015).

This chapter attempts to identify complexity drivers within the system of global automotive production. Therefore, variables determining network configurations scenarios are derived in the following step. These are to be recognized when developing a quantitative evaluation approach (mathematical model) in chapter three.

2.3 General requirements of the network configuration model

Deriving from the above conducted analysis following variables need to regarded for the cost assessment in production, sourcing, logistics and trade barriers. The total demand per vehicle model and target market need to be estimated. Also the number and location of available production plants including production capacities should be known. The production line design of a plant determines which models and variants and therefore which specific parts, components and pre-assembled car formats can be processed in production. For cost assessment production plant assets and further factor costs need to be included amongst others. Due to parts and components price and local sourcing and local value creation requirements' suppliers and volumes per part and production plant are to be selected. Regarding the design for transportation possibilities, transportation distances between supplier and producing plant for parts and components as well as between plant and target market for the transport of complete vehicles need to be analyzed. The choice of the transportation mode and of a logistics service provider determine transportation costs for parts and complete vehicle transport. It is necessary to include tariff costs which differ strongly between the import of part, components, pre-assembled cars and complete vehicles. Furthermore, country specific regulations evoke restrictions for local content and local value added which need to be integrated because they limit the selection of suppliers and determines the production line design. Local content requirements can lead to the development of local suppliers which can be regarded as an additional cost factor.

3 Decision support model for sourcing strategies in the market development process

Based on the analysis this paper proposes an approach to support the decision finding process in finding the network configuration that enables demand fulfillment in all target markets at minimal costs for automotive emerging market businesses. Depending on the legal and supply chain-oriented regional situation, the model enables a cost-optimized adaption of the sourcing strategy. First, the decision areas of the model will be described in detail. Subsequently, the mathematical model description is presented.

3.1 Decision areas of the decision support model

The areas of the decision support in this context are closely linked with the concept of supply chain management and can be seen as a subtask of it (Ferber 2005; Schmaußer 2011). Supply Chain Management can generally be divided into four main processes, namely procurement, production, distribution and sales, which have different planning tasks regarding short-, mid- and long-term planning horizons (Fleischmann et al. 2015). The approach described in this paper focuses on the long-term decision areas supplier selection and allocation of vehicle production in the selected production plants. Furthermore, in the context of market development processes for the automotive industry trade barriers are considered and the minimization of the total costs for the fulfillment of market demand including production and distribution to the target market will be part of the model. Therefore, specific selection and allocation restrictions apply, which were analyzed in chapter 2. Following the task allocation of the Supply Chain Management Task Model (Kuhn, Hellingrath 2002), these tasks fall within the scope of the supply chain design problem (Parlings et al. 2013) and span the main supply chain processes procurement, production and distribution because of the “comprehensive character of the strategic planning” (Fleischmann et al. 2015).

The supplier selection task defined in the decision support model starts after the procurement department conducted a preselection of available suppliers for each predefined part or component. The model chooses the supplier for a specific part or module of a specific vehicle model, which will lead to the minimized costs considering the price of the part, the packaging, handling and transportation costs from the supplier to the selected production plants and tariff trade barrier costs if apply. Depending on the agreements with the supplier, the logistics cost can be taken over by the supplier and included in the parts costs. However, in the context of total landing costs theory (Trent, Roberts L. 2009), these costs have to be included in the cost consideration, as they will affect the profit either way. Local content restrictions of the target market will be included on a vehicle basis, if a local production plant is taken into consideration. However, in this model, only the first-tier suppliers are taken into account.

The allocation task of the model uses the optimized supplier selection data in order to optimize the allocation of the demanded production volume to the selected production plants. It minimizes the sourcing costs, production costs as well as the distribution costs of completely build up (CBU) vehicles from the production plants outside the target market to it. The sourcing costs are calculated for each vehicle and plant. The production costs are integrated as an input data per vehicle and production plant since the optimization of the production costs is not in the focus of this paper. Research on global production optimization can for example be found in (Meyer 2006; Bundschuh 2008; Schmaußer 2011, 2011), respectively. In the context of the development process in the automotive industry, the partial production of vehicles has to be considered (s. chapter 2). This problem is in a first step simplified in the model by integrating possible partial vehicle states as a supplied part in the input data, where the supplying production plants are listed as possible suppliers. The listed price for this module corresponds to the transfer price of that part from the production plant. In the restrictions area it will be defined, which plants are allowed to source these modules from other plants, what is actually a representation of the partial production strategy. The distribution costs contain the packaging, handling and transportation costs for CBU vehicles from each plant outside the target market as well as costs for tariff trade barriers. Restrictions apply for the minimum and maximum production capacity for each plant and through non-tariff trade barriers in the case of a production plant in the target market.

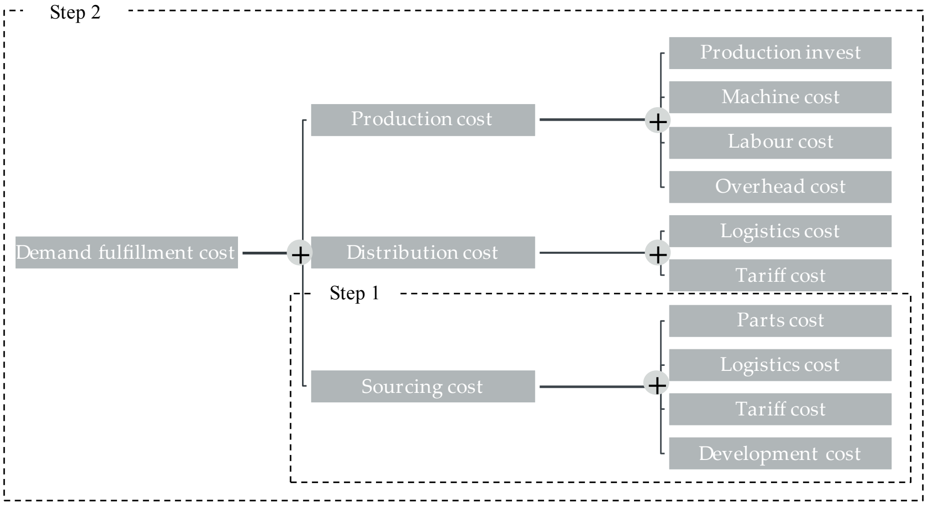
3.2 Mathematical description of the decision support model

In order to determine the optimal sourcing strategy for the local demand fulfillment, the main cost drivers have to be evaluated and the scenario with the lowest total landed cost has to be calculated. Therefore, a mathematical optimization model is used, which minimizes the total costs. The cost drivers taken into consideration are separated into three groups, namely production cost, distribution cost and sourcing cost. The former compromises the expenses for manufacturing, labor, new invests as well as indirect production costs such as costs for the production facilities. The distribution cost includes the expenses for logistics and handling as well as the tariff costs for the import of completely build up cars (CBU) from main plants to the target market. The third group, the sourcing cost, compromises the costs for all supplied materials and preassembled modules, the transportation and packaging costs to handle the supplied parts, the tariff costs as well as supplier development costs. In this paper the focus will be upon the sourcing cost in particular. The basic structure of the model is shown in Fig. 1.

The production volume for each plant and model as well as the binary decision for the selection of a supplier for each part and model at a specific plant will be the decision variables. Furthermore, non-tariff trade barriers and other restrictions are formulated as constraints. To classify the decision support model, the main characteristics of the model have to be defined:

- Static: The variables are assumed to be constant over the time period.
- Deterministic: The variables are integer or binary numbers.
- Linearity: The target function as well as the constraints are linear.
- Non-negativity: None of the variables may be negative.

Fig. 1.



On the basis of the defined model characteristics a binary and integer linear programming approach for the decision support model is selected. The model is written in MPL 5.0 (mathematical programming language) and solved with the standard solver Gurobi Optimizer version 6.0. The first step of the optimization focuses on the selection of the supplier with the total minimum cost per supplied part or module for each model and plant. This problem is formulated as a binary linear program:

$$\boldsymbol{MIN}\left(\boldsymbol{c}_{l,j}^{S}\right), \tag{1}$$

where

$$c_{l,j}^{S} = \sum_{r\in R}\sum_{s\in S}\Bigg(PC_{l,j,r,s}\left(1 + CR_{l,j,r,s}^{PC}\right) + SD_{l,j,r,s} + PV_{l,r}\sum_{m\in M}\left(TD_{l,j,r,s,m}^{PC}\cdot TR_{m}^{PC}\right)\Bigg)\,\alpha_{l,j,r,s} \tag{2}$$

The sourcing cost $c_{l,j}^{S}$ per vehicle model $l\,(l \in L)$ and production plant $j\,(j \in J)$ are minimized by multiplying all considered cost factors with the binary decision variable $\alpha_{l,j,r,s}$, where the index $r\,(r \in R)$ represents each defined part or component and the index $s\,(s \in S)$ represents each supplier per part or component. The considered cost factors are in detail:

the price for the supplied part or component $PC_{l,j,r,s}$. Tariff costs per part, which is calculated by multiplying the parts price with the according customs rate $CR^{PC}_{l,j,r,s}$. Therefore, the data must be edited in a form, where it is clear, in which countries the production plants and the supplier plants are located. Supplier development costs $SD_{l,j,r,s}$, especially for suppliers from less developed automotive industry markets, in order to enable them to deliver the right products in the specified quality are also integrated. Finally, the logistics cost are calculated by multiplying the volume of a part $PV_{l,r}$ with the sum for each transportation mode m ($m \in \{Land, Sea, Air\}$) of the product of the transport distance per part $TD^{PC}_{l,j,r,s,m}$ from the supplier plant to the production plant and the transportation cost rate TR^{PC}_{m} per volume and distance unit. The result is summed up over r and s.

After defining the objective function, the constraints have to be specified. Therefore, the local content restrictions mentioned in chapter 2 are transformed into mathematical descriptions.

$$\sum_{r\in R}\sum_{s\in S}\left(PC_{l,j,r,s}\cdot\alpha_{l,j,r,s}\cdot W_{l,j,r,s}\right) / \sum_{r\in R}\sum_{s\in S}\left(PC_{l,j,r,s}\cdot\alpha_{l,j,r,s}\right) \geq LPC_{l,j} \tag{3}$$

$W_{l,j,r,s}$ represents an assignment parameter, where the local suppliers are defined. The parts costs over all parts from local suppliers is divided by the total parts costs. This rate should be equal or higher the specified local content rate $LPC_{l,j}$. Furthermore, three assignment constraints have to be defined. First, it has to be checked, if the processing of a specific part is allowed in a specific plant. Therefore the data vector $Z_{j,r}$, which contains the assignment data, is used in the following inequation:

$$\sum_{s\in S}\alpha_{l,j,r,s} \leq Z_{j,r} \tag{4}$$

Next, it is made sure that only one supplier is selected in this special case of the market development process. If another sourcing strategy is needed (dual sourcing, multiple sourcing) the optimization has to be redone without the first selected supplier in order to select another appropriate supplier.

$$\sum_{s \in S} \alpha_{l,j,r,s} = 1 \tag{5}$$

Finally, it has to be checked, if all parts for a vehicle are taken into account:

$$\sum_{r \in R} \sum_{s \in S} \alpha_{l,j,r,s} = R \tag{6}$$

The optimization problem for the demand fulfillment task, where the cost minimal distribution of the vehicle production per plant and vehicle model is defined, can be formulated as follows:

$$\boldsymbol{MIN}\ (\boldsymbol{c^P} + \boldsymbol{c^D} + \boldsymbol{c^S}), \tag{7}$$

where

$$c^P = \sum_{l \in L} \sum_{j \in J} \left(\left(MC_{l,j} + PI_{l,j} + WC_{l,j} + OC_{l,j} \right) \cdot x_{l,j} \right) \tag{8}$$

$$c^D = \sum_{l \in L} \sum_{j \in J^*} \left(\left(TP_{l,j}^{CBU} \cdot CR_{l,j}^{CBU} + VV_l^{CBU} \sum_{m \in M} \left(TD_{l,j,m}^{CBU} \cdot TR_m^{CBU} \right) \right) x_{l,j} \right) \tag{9}$$

$\forall\ j \neq$ *local production plant*

$$c^S = \sum_{l \in L} \sum_{j \in J} \left(c_{l,j}^S \cdot x_{l,j} \right) \tag{10}$$

The total landed costs constituted of the total sourcing cost c^S, total production costs c^P and total distribution costs c^D are minimized. c^S will use the results from the first optimization step $c_{l,j}^S$ and multiply it with the production volume per vehicle model and production plant $x_{l,j}$.

The production costs per vehicle model and plant consists of the machine cost $MC_{l,j}$, production invest $PI_{l,j}$, labor costs $WC_{l,j}$ and overhead costs $OC_{l,j}$. It will be integrated in total and multiplied by the production volume in order to calculate the total production costs. The calculation of c^D is designed as the multiplication of the transfer price per CBU vehicle $TP_{l,j}^{CBU}$ from a production plant outside the target market ($j \neq$ *local production plant*) with the according customs rate $CR_{l,j}^{CBU}$, which will be added to the logistics costs and multiplied in total by the production volume. The logistics cost will be calculated in the same way as above by summing up the multiplication of the transportation distance per transportation mode $TD_{l,j,m}^{CBU}$ and the transportation cost rate TR_m^{CBU} and then multiplying it with the vehicle volume VV_l^{CBU}. Each formula (8) – (10) will be summed up by the indices *l* and *j*.

The constraints for the second step are the following descriptions:

$$\sum_{j \in J} x_{l,j} = MV_l \tag{11}$$

Equation 11 makes sure that the exact market demand volume MV_l for each vehicle model is produced in total over all production plants *j*.

$$CC_{l,j}^{MIN} \leq x_{l,j} \leq CC_{l,j}^{MAX} \tag{12}$$

Finally, the capacity constraints of each plant has to be considered. This is done in formula 12. The production volume must be higher or equal than the minimum production capacity $CC_{l,j}^{MIN}$ per vehicle model and plant and smaller or equal the maximum production capacity $CC_{l,j}^{MAX}$.

4 Validation of the model

The developed optimization model to support the decision finding process for sourcing strategies in the market development phase is validated through a computational analysis. The results are used in order to analyze decision changings of local production decisions if tariff and non-tariff trade barriers apply. Therefore, five scenarios are defined (Tab. 1).

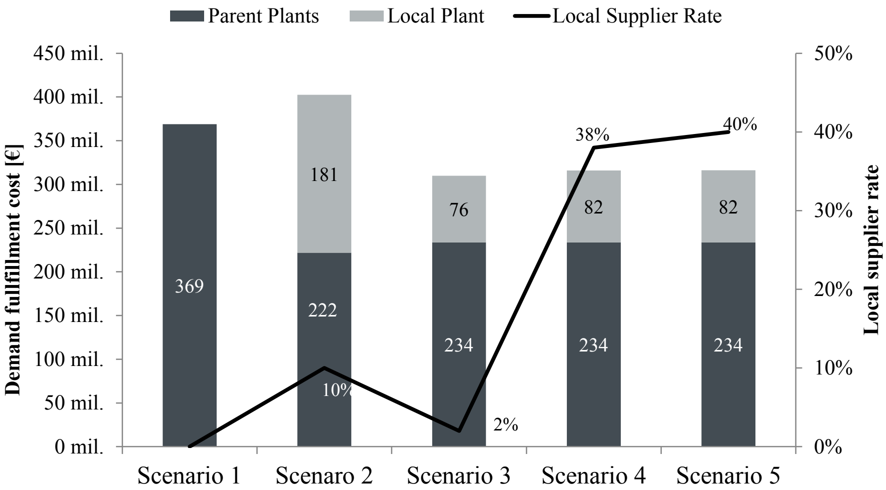
Table 1.

Scenario	Framework condition			
	Parent plant production	Local plant production	Non-tariff trade barriers	Explanation
Scenario 1	Complete production	No production	Not considered	The whole demand volume will be produced in the parent plant. No local production will be performed.
Scenario 2	Complete production	Complete production	Not considered	All production steps for a vehicle will be conducted either in the parent plant or the local plant. No partial vehicle production will be performed.
Scenario 3	Partial and complete production	Partial production	Not considered	In the parent plant the vehicles will be produced completely or all production steps excluding the final assembly are conducted. In the local plant only the final assembly is performed.
Scenario 4	Partial and complete production	Partial production	Considered	Same breakdown as scenario 3, but here the non-tariff trade barriers are included.
Scenario 5	Partial and complete production	Partial production	Extended	Scenario 4 is extended by the integration of a local content rate.

The analysis has been conducted for the following case study for a Germany based OEM from the automotive sector. The numbers have been anonymized from the real case. The target market is India. The demand for one specific vehicle model VH1 from the viewed OEM in the target market is about 10.000 vehicles. Each of the model can be produced locally in the same plant (PP3) as well as in two parent production plants PP1 and PP2. The applying tariff rate in the target market for the import of CBU vehicles from Europe is 75% depending on the vehicle model and engine size (European Commision 2015). Relevant non-tariff trade barriers in the target market are the provision to conduct two significantly relevant production steps locally, e.g. the assembly of the engine as well the assembly of the brake system, in order to profit from a decreased tariff rate of 30% for the import of the knocked down vehicle parts (Sivakumaran et al. 2015). A further decreased import rate of 15% will be applied, if the parts are not imported as kits but on own logistic concepts. But this scenario will not be considered in this case. A local content rate is not specified. In the parts lists, which are defined per production step, for every part at least one possible supplier is assigned. The supplier base spans 10 markets including the European Union, ASEAN and Mercosur. For 45% of the parts a local supplier can be chosen. The tariff rates for the supplied parts to the production plants have been gathered through the European Market Access Database (European Commision 2015) and OEM own analyses. Additionally, production invest for a local production is integrated. To solve the case study, the Gurobi solver was used on a standard personal computer, with a Core i7 CPU (2.7 Ghz) and 8 GB memory. The calculation time was less than two minutes.

The first two scenarios only consider a full production in the plants (body, paint and assembly). In the other scenarios the local plant PP3 is only capable to conduct a specific range of production steps. The other steps have to be completed in the main plants. Additionally, in the first three scenarios the cases are calculated without considering the non-tariff trade barriers Finally, the last case is calculated with a fictive local content rate of 40%, similar to the ones in Russia or Thailand (Sivakumaran et al. 2015; EABC 2012). Due to the fact that the data is highly sensitive, the numbers were anonymized. However, the results are presented in Fig. 2 represent the qualitative results as well the correct percentage differences between the scenarios.

Fig. 2.



It can be seen that the first two scenarios show by far the highest demand fulfillment costs. In the first scenario the parent plant with the lowest total costs is chosen to produce the whole market demand. In the second scenario a local production capacity of 4.000 vehicles in PP3 is specified in order to show the difference to scenario one. Based on this results, under the circumstances of this case a local production is recommended. However, a complete local production of the vehicles in this production volume range is unrewarding, as scenario 2 is more expensive than the scenarios 3 and 4. This is due to the fact that the investment for a full-fledged local production plant is highly expensive. The requirement to conduct two significant production steps locally does not change the decision of performing the final assembly locally, thus it is more expensive than without the non-tariff trade barrier (scenario 4 is cheaper than scenario 2). However, the initiation of local content requirements will not change the decision in this case. A local content rate of 40% will increase the demand fulfillment cost slightly to the previous scenario even though the previous scenario had already a local content rate of 38%. This is due to the fact that the most newly selected local suppliers have to be developed in order to supply the right parts in the right quantity and quality. This comprises process development as well as IT-integration. Additionally, the parts costs are commonly more expensive than the ones from the established suppliers because of the lower sourcing volume even though the Indian supplier market is classified as cheap and developing in other research publications (Schmaußer 2011). The results also show that local suppliers will be used if they are already developed because of the lower logistics and tariff costs. Additionally, this decreases the exchange rate risk in the context of natural hedging (Dielmann, Häcker 2012).

It can be concluded that the tariff rate is not the only decision aspect for a local production. In fact, the non-tariff trade barriers have a similar decision importance. Furthermore, with a rising production volume the development of local suppliers is recommended as this development costs will be rewarded with decreases logistics, tariff and exchange risk costs.

5 Conclusion

The paper introduces a new mathematical model for the assessment of emerging market developing strategies including non-tariff trade barriers. Therefore, different impacts are introduced and transferred into a decision support model to show the significant influence of those impacts on the economic feasibility of market entrance business cases. The findings presented in this paper do contribute to both research as well as practice. With regard to research, the findings contribute to further developments of process models and frameworks in the context of automotive market entry process research. With regard to practice the existing planning processes can be focused using the mathematical model, which can lead to shorter planning durations. As a result, the car manufacturers are able to better react to the dynamic environment in the emerging markets.

The relevance of non-tariff trade barriers will increase in future. Therefore, the model has to be extended through future research. The next step is to integrate the dynamic aspect of changing parameters during time as well as the integration of additional trade barriers and their influence on the decision making process.

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The role of digital technologies in the innovation of collaborative networks: the case of the ornamental stones in Portugal

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Abstract
This exploratory research outlines an innovative business model for the ornamental stones, in Portugal, targeting World Class Manufacturing. Research questions arise from an inductive approach empirically based on a participant-observer that participated in JETSTONE and INOVSTONE, two important Mobilising Projects for the cluster. A collaborative network pursuing a Service Systems view, leveraged by digital technologies was proposed based on a 3-stage development facilitated by the ARCON framework (ECOLEAD project), as follows: development of a general VBE/VO model completed by knowledge coming from BIM, Industry 4.0, IoT and Service Science backgrounds, in order to build up a specific model to the ornamental stones Industry. Finally, the specific model should be verified by case studies as demonstrating instances. While the generic VBE/VO might be customized to other domains, the specific model generates a representation of the Industry and the case studies serve as instances to verify it.

Keywords: Value Networks, Collaborative Networks; Virtual Organizations, Virtual Breeding Environments; Industry 4.0, Internet of Things (IoT); Building Information Modelling (BIM); Service-Dominant (S-D) Logic, Service Science.

1. Introduction

This article reports an inductive study with an exploratory purpose that is based on the extensive empirical knowledge of one of the authors. In fact, he has been part of the change process of the industrial cluster that has re-invented the ornamental stones sector, acting as a key participant-observer. This investigation aims at discussing the adequateness of a set of research questions that should establish relevant guidelines to orientate the development and confirmation of a conceptual business model addressing sustainable operations within the ornamental stones cluster. This should be able to leverage the competitive advantage both in Portugal and in the international arena according to the demographic characteristics of the sector and of its business agents.

This innovative organizational model is expected to follow a collaborative networked approach, to be sustainable, to consider the Service Science view and to incorporate the state-of-the-art of the digital technologies, as regards concepts such as the Building Information Modelling (BIM), the Industry 4.0 and the Internet of Things. Therefore, it should be developed and presented a preliminary outline of the features for an updated Information and Communication Technology (ICT) interface to support the network business processes that enable each organization to magnify its core competencies, resources and skills with complementary ones from the virtual community. Moreover, the ICT should be coordinated on the three levels of the Value System interaction - intra-/inter-partner and integration, in order to reduce the complexity of the design and implementation (Fuchs, 1997) of a system to realise and capture the value of a business opportunity (Katzy and Obozinski, 1998).

This is a significant topic since that the *Global Construction 2025 Report* (*in* HM Government, 2013) estimates a 70% growth for the construction sector, until 2025, at a global level. In the launching year of the BIM, i.e. 2013, the UK saved £840 M because of its use in two public projects (UK Government, 2013). Moreover, the United Kingdom is a major player, holding a top ten global market position and being part of a World Class Construction industry (Global Built Asset Performance Index, 2014).

Motivated by these results, the UK Government started a strategy towards the implementation of BIM in the Architecture, Engineering and Construction (AEC) industry, the Digital Built Britain (DBB). It aimed at increasing the annual profit in £10 Bn/year, in the domestic marketplace, by reducing waste and increasing competitiveness through the general use of BIM after 2016. These performance indicators anticipate the size of the potential savings in the international market, in the industry where the ornamental stones belong, as well as of the importance of this economic sector.

Therefore, the section 2 of this paper shows the economic importance of the ornamental stones, in Portugal, that goes far beyond €1000 M/year, acting as a cornerstone of the regional development by supporting a traditional cluster of the national industry. In addition, the leading purpose of the of the natural stone industry supported by a strong technological interface is disclosed. The aim is to assure the survival by pursuing a recognized world class excellence. Finally, the two earlier successful mobilizing projects were revisited, i.e. JETSTONE and INOVSTONE, as the context to frame the forthcoming organizational and technological steps. These developments should fit the industry nature, related to small dispersed SME, but simultaneously part of a hostile international environment of strong competition. Then, using a collaborative network for organizational modelling appears as an attractive path to proactive creation of value. From this point onwards research questions are set. Their interest and mechanics will be discussed in a subsequent section by considering the knowledge areas proposed as significant through empirical induction by the participant-observer taking into consideration not only his accumulated experience but also the progress of the competitive context.

However, before the discussion of the Research Questions taking place, the research methodology, i.e. the expected path to link the RQ to the expected outcomes is addressed (section 3). Several leading authors in collaborative networks were considered to inspire and support the choice of a reference model to operationalize the value system of the ornamental stones cluster. This model is part of the ARCON framework which includes both the endogenous and exogenous elements of a collaborative organization operationalized in a network. It also enables three levels of representation, as follows: general, specific to the ornamental stones cluster and case study instances.

Section 4 promotes the discussion of the empirical assumptions that were preliminarily considered by the participant-observer, by performing a literature review based on scientific journals. Not only the contents of the choices was checked, but also their relationships in the definition and operationalization of the key dimensions of a new model that should be adequate to the business, organization and current operations demands in the ornamental stones industry. Firstly, the role of the collaborative networks and virtual organisations is found as a relevant alternative, after the strategic context being set. Secondly, the impact of the new trends of the technological infrastructure in the collaborative model proposed for the ornamental stones is discussed. The potential contribution of the digital technologies to the sustainability of the collaborative model is approached under a Triple Bottom Line view. Finally, the strategic requirements of a Service-Dominant Logic are analysed in their proposal, value network relationships and progress needs. A significant gap was found out and a solution was proposed based on the Service Science domain.

Section 5 provides a summary of the core aspects of the article and revisits the research questions. It also explicits the expected innovative contributions to theory, research and practice.

2. Competitive environment of ornamental stones

Importance of the ornamental stones cluster in Portugal

Portugal does produce a broad range of ornamental stones, playing a major role in the exportation of these materials as the 8th world producer (ASSIMAGRA, 2014). The industrial cluster includes 17.000 of direct jobs, in 2.700 companies, acting on several activities, such as extraction, manufacturing, advanced machinery and tooling. The cluster turnover is around €1 Bn/year and the coverage rate of total imports by exports is 768%.
These data are completed by EUROSTAT and *Direção Geral de Geologia e Energia* (DGGE), as follows. In the early 2000s, exportations of ornamental stones were about €207 M€/year in 2004, i.e. 50% of the cluster activity. Moreover, these figures also represented more than 50% of the Portuguese exportations of mineral substances, in 2004. Marble and Limestone were the most exported (≈63%), followed by Granite and similar stones (≈19%), Stone to Sidewalk (≈15%) and Slate (≈3%) (Schists).
The excellence of raw material, the robustness of the industry cluster despite being a traditional sector, the flexibility and adaptability to new market demands are the critical success factors that support the ranking of Portugal amongst the tem major world players. This is a significant economic activity for the national economy and also for rural development that is among the top industry sectors as regards Gross Added Value (GAV).

Main purpose of the natural stones cluster in Portugal

The natural stones cluster aims at continuing to increase exports in a sustainable way. The main cluster drivers were identified, as follows:

- To continue to develop a leading industry, as regards both technology and organization, under a World Class Manufacturing paradigm;

- To leverage the competitive advantage with state-of-the-art technology, developed in Portugal, aiming at its transference/trading to other significant world players;
- To improve the «supply chain» operations performance by broadening variety; developing customization; reducing time-to-market; decreasing cost; improving quality and business sustainability becoming more environmental friendly;
- To create the appropriate conditions to reinforce the credibility of Portuguese players in the international arena, e.g. as regards the satisfaction of both higher volumes and higher variety levels;
- To improve the image of the natural stone products of Portugal and so, adding value to the industry;
- To develop a more demanding collective behaviour in the cluster, as regards environmental friendly operations.

The industry has been recognizing the co-creation of value both internal and externally to the «supply chain» as the path to increase competitiveness and so, the long term sustainability of its operations towards survival assurance. However, the pursued sustainability is a broad approach that also concerns the well-being of the stakeholders, the concern with the depletion of non-renewable and renewable resources, the removal, treatment and disposal of waste, the survival of the members of the industry and the economic problems of target market communities. This view is aligned with the principles of sustainable development proposed by Elkington (1997), Hawken et al. (1999), Porritt (2001) and, Dyllick & Hockerts (2002).

Anticipated future of the ornamental stones in Portugal and research questions

The ornamental stones cluster has suffered the positive impact of a few Development Mobilising Projects targeting the development and application of a new generation of technologies, concepts and practices, as follows: (i) adding flexibility to manufacturing and promoting agility of customized projects; (ii) reducing the raw material waste; (iii) improve energy efficiency; (iv) upstream integration in the supply chain; (v) increasing productivity; (vi) promoting new product development; (vii) improving the working conditions; (viii) improving product and service quality; and, (ix) being more environment friendly.

The JETSTONE Mobilising Project operationalized the first stage of this path, by setting up a consortium of 10 companies and organisations from the National Scientific and Technological System (SCTN). 15 innovative prototypes of advanced machining centres used by tenths of firms were the main visible outcome, in 2008. The INOVSTONE Mobilising Project (2013) resulted from a consortium of 16 organisations and generated more 8 prototypes, their integration in modern layouts and addressed new production concepts. These projects contributed to the creation of 2.000 jobs and a positive input of €180 to 240 M for the Portugal's trade balance. Thus, the wealth created by these projects, in a 5 years' period, was 34 times bigger than the investment. The lesson to be learnt from practice is that these projects created a leverage effect across the cluster that would be impossible to achieve from non-coordinated action of individual companies.

Lately, different concepts about creating value from «*Collaborative Networks* (CN)» (Camarinha-Matos & Afsarmanesh, 2007) have been proposed. However, they require a research effort towards their operationalization. In fact, several projects concerning «*Collaborative Networks* (CN)», «*Virtual Breeding Environment* (VBE)» e «*Virtual Organizations / Virtual Enterprises* (VO)» have been financed, since the European Union's fourth research and technological development (RTD) framework programme (1994-98). One of these was the ECOLEAD project developed under the FP6.

Several researchers have argued that the firms' competitiveness will progress across new management models concerning the integration of their operations in value networks (Lusch et al., 2009) aiming at collecting synergies from these collaborative trends. These models include ICT interfaces (e.g. Fuchs, 1997 and Katzy, 1999) that have to be updated with the outcome from digital technologies, either in general, or coming from a AEC background, such as the Building Information Modelling (Kim et al., 2015) or the CAD 3D (Björk & Laakso, 2010). In this way, the advanced manufacturing technologies coming from the JETSTONE and INOVSTONE projects are a critical requirement to assure the internal integration of the partners, a cornerstone for the inter-partner coordination and control required for the external integration in a value network.

Despite organisational and technological development follow the direction pursued by the classical collaborative models of Bernhard Katzy and Luís Camarinha Matos (*e.g.* Silva & Almeida, 2016), there is new knowledge to be considered and integrated. Thus, a new reference model (*vide* Romero & Molina, 2010) for the ornamental stones should be developed. The Digital Economy and the Internet of Things are examples of new concepts and technologies that further power models such as the Industry 4.0. On the other hand, some authors have been arguing for a change from a product-dominant to a service-dominant logic (Edvardsson & Tronvoll, 2013), where stakeholders are considered as resources of the value chain.

This is the background, both from practice and theory that accommodates the following preliminary research questions derived in an inductive way

- RQ1 – How may a collaborative typology fit the requirements of the ornamental stones cluster made up of familiar SME?
- RQ2 – What is the specification that a collaborative network for the ornamental stones cluster should meet, in order to be built an effective framework, as regards:
    i. Common organizational structuring;
    ii. New business models;
    iii. Shared ICT infrastructure;
    iv. Manufacturing technologies.
- RQ3 – Why should both individual organisations and also the cluster of the ornamental stones pursue the implementation of a collaborative environment?
- RQ4 - Which methodological path is adequate to the design, development, implementation and operation of a collaborative environment in the ornamental stones cluster, in Portugal?

3. Outline of the methodological path to be pursued

The ECOLEAD Reference Model (e.g. Romero et al., 2008; Romero & Molina, 2010), comes from the ARCON framework, which covers both endogenous and exogenous elements of a collaborative organization arranged in a network (e.g. Silva & Almeida, 2016). This model appears to be a good starting point for the operationalization of the *Value System Lifecycle* (VSL) of Fuchs (1997) and Katzy (1999). The VSL is a framework to support the design of

Virtual Organisations by covering all the stages of their lifecycle based on a collaborative network of competences that are made available by the partners. This is what would later be called a *source network* or a *breeding environment* (Silva & Almeida, 2016). On the other hand, this model should be completed by knowledge coming from such domains as BIM, Industry 4.0 and S-D logic.

This is how the future developments of the ornamental stones is anticipated, within the context of the 4th Industrial Revolution. The current knowledge of the computer science is applied to the development of a value system based on a collaborative network that emulates and focus on relationships, interfaces and partnerships. These three dimensions are the core part of (i) the collaborative processes that overcome the focus on the physical resources; (ii) the co-created service value that overcome the (physical) product specifications; (iii) the implementation of a *Virtual Organization Breeding Environment*.

Within this context, the *instantiation* methodology looks adequate as a good fit (Romero et al., 2008), enabling the following four main steps:

i. To critically appreciate the usefulness of the *Reference Model* from ECOLEAD, to consolidate it and to develop it into a general model leveraged by the current ICT potential, leveraged by the S-D logic;

ii. To further develop the general into a specific model adequate to the ornamental stones cluster;

iii. To empirically test the resulting specific model in a case study from the ornamental stones, implementing it or detailing recommendations for its implementation;

iv. To analyse the external validity of the general model specification through an analytical approach.

4. Discussion of the proposal obtained through an inductive approach

Strategic positioning of the ornamental stones industry

Procurement is a relevant function, specially when a focus-company is outsourcing operations. However, the e-procurement is still residual in the ornamental stones (Silva, 2013) because the required information is neither structured, nor in a digital format in the AEC sector (Grilo & Jardim-Goncalves, 2012). Moreover, the use of BIM at a global level (Liu et al., 2015) that is being imposed by governments such as the UK one (HM Government, 2013), places new challenges to the AEC stakeholders, as regards procurement (Grilo & Jardim-Goncalves, 2012). The consequences of these demands are still unpredictable (Merschbrock & Munkvold, 2015). Nevertheless, the Digital Built Britain (DBB) strategy aims at making the UK a world leader in BIM, with expected outcomes of £10 Bn/year profit, coming from more competitiveness and bigger exports.

The virtual building design in BIM is obtained by adding up elements in digital format IFC (Won et al., 2013). Objects are specified in an open format of eight dimensions (ISO 16739:2013), from where the BIM modeler, now the customer, might appreciate materials diversity, geometric adaptability, originality, price, lead time, ecological footprint, maintenance cost during the whole lifecycle, safety (Jung & Joo, 2011), i.e. their fingerprint.

The next step is the project approval by the adequate authorities and, then, parts will be allocated to suppliers according to the planning outcome of BIM. The construction stage will, then, start (Hamil et al., 2014). Despite the building owner might buy the parts freely, the elements' fingerprint has to strictly follow the project approval requirements (Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013). Thus, choices during design might very well constrain vendor's selection, unless a new formal approval is obtained (Malsane, Matthews, Lockley, Love, & Greenwood, 2014). In this way, the BIM modeller, typically an architect, will assume the role of decision making customer. Moreover, it is mandatory that the building is constructed according to the plans, in order to be obtained the expected result.

As the very first consequence of this new procurement model, the supply chain stakeholders must make public all the commercial and technical information concerning their products in open format IFC (Hamil et al., 2015). Being the prices public, the chosen option should have a more effective value structure, where reducing waste through continuous improvement will perform a relevant role (Yang et al., 2011) in competitiveness.

In the specific case of ornamental stones there will be an additional determinant for the BIM modellers to prescribe this type of solution. If the objects in the libraries do exhibit a rigid spacial geometry the IFC objects will not adapt to building irregular shapes and, so, material differentiation that characterizes Portuguese ornamental stones will be lost. Therefore, the stone objects have to be dynamic at the moment when they are inserted in the BIM platform (Heidari et al., 2013), in order to be adaptable to the building, during the design stage (Soediono, 2003). This challenge is even bigger, because these elements are manufactured from natural raw materials, where every block is unique (Galetakis & Soultana, 2016). Thus, there is a conflict because a major advantage of BIM usage concerns the standardization of the virtual objects to be part of the building, in order to bring in more visibility to the business and to the procurement process itself (UK Government, 2011). On the other hand, making available ornamental stones' objects adaptable to the building and to the BIM modeller/prescriber requirements might become a competitive advantage, if information interoperability is assured.

Beyond taxes becoming easier to update in real time, other expected advantages of BIM are, as follows: 33% reduction in the costs of construction and maintenance during the whole lifecycle; 50% reduction in construction time for both new buildings and refurbishing; 50% reduction in total CO_2 emissions in the construction industry (HM Government, 2013). The assumption of these objectives will put pressure on all the stakeholders of the AEC supply chain. As regards the ornamental stones, these targets together with the adaptability requirements of the virtual object do impact the way operations are currently organized in the supply chain and also, the existing organisational model. If no action is taken, the survival of the ornamental stones industry is seriously threatened. Therefore, an operations model that assures the sustainability of companies within a BIM context has to be addressed. In fact, several researchers have tried to address the advantages of collaboration in sustainable competitiveness, when facing more hostile environments, with more complex products, more dynamic ones with more changing requirements and also, more demanding contexts, as regards quality and accountability (Feller et al., 2013). Therefore, the collaborative network model appears to fit well within these dimensions of the competitive context of the ornamental stones.

Expected role of collaborative networks and virtual organisations

According to Kropotkin (1903) cooperation and mutual aid are determinants of the evolution and survival of the species. The collaborative work in organisations helps to overcome individual limitations, specially in SME where skills and resources are very limited (Camarinha-Matos & Afsarmanesh, 2007).

The ornamental stones cluster both in Portugal and in the World is mainly made up of familiar SME (UK Government, 2011). Therefore, the lack of both economies of scale and scope might be a serious drawback of sustainability within a BIM context. For this reason, an operations model promoting inter-organisational collaboration is definitely a solution to be seriously taken into account. In fact, the BIM modeller will share information concerning the progress of the virtual building with other professionals, which might result into shared innovation leading to value creation (Edvardsson & Tronvoll, 2013).

Several types of collaborative organisations have been introduced such as *Industrial Clusters*, *Industrial Districts*, *Business Ecosystems* (Akaka et al., 2015). Usually, they put together organisations sharing common interests within a certain region that build up a coordinated response to business opportunities that would not be individually affordable (Romero et al., 2008). In addition, the quick progress of the ICT put together with globalization, but including requirements for increased customization has led to the conceptualization of new types of long term strategic alliances such as the *Virtual Breeding Environments* (VBE) (Afsarmanesh et al., 2009).

A VBE is a long term consortium of organisations (Camarinha-Matos & Afsarmanesh, 2007), committed to adopt common operations principles and to share infrastructures pursuing the goal of being prepared to work together in a collaborative network at any moment (Afsarmanesh et al., 2009), generating Virtual Organisations (VO) that might be able to operationalise value co-creation. Therefore, a VO is a model of collaborative operations in the short term, designed within a VBE to respond to an emergent business opportunity by integrating knowledge, skills and other resources (Romero, 2009).

The VBE concept applied to the ornamental stones appears to be an effective way to overcome some weaknesses of the sector. VO might overcome the consequences derived from the small size of the cluster firms, e.g. the lack of knowledge and skills of individual organisations, the diversity of raw materials, the high customization requirements, the shorter lead times being asked, the high costs of promotion and market entry, and the high structure costs. However, developing a shared ICT infrastructure by all the VBE members is a *sine qua non* condition (Afsarmanesh et al., 2009).

In the last 15 years, the ornamental stones industry has incorporated both ICT and advanced manufacturing technologies, as previously mentioned (JETSTONE and INOVSTONE Mobilising Projects). Thus, these companies make use of the state-of-the-art production technologies in their internal operations. However, to work within a VBE/VO paradigm there is a need to develop inter-organisational systems that respect common interoperability protocols. So, the development of the requirements for this interface is a relevant part of the technological ICT infrastructure to be implemented.

Trends of the technological infrastructure and impact on the collaborative model

Many researchers consider that the 4th Industrial Revolution already started. Some call it Industry 4.0 (Kagermann et al., 2013), where real and virtual worlds meet in the Cyber-Physical Systems (CPS) (Fair et al., 2012). Industry 4.0 was coined by the German Government in 2011 (Produktionsprozess & Prozesskontrolle, 2014) to describe a leadership strategy from the German Industry (Mosterman & Zander, 2015). The idea was to use digital technologies to facilitate the interaction between machines and products (Fair et al., 2012) to reverse the industrial decline in Europe (Kagermann et al., 2013). Moreover, the potential to improve collaborative innovation (incremental and radical) within the AEC supply chain might be magnified by digital technologies (Eppler, 2008). Therefore, a 20% increase in value creation until 2020 is expected (Davies, 2015).

Within the ornamental stones Industry, it is expected that machines' communication might be promoted inside CPS, without being dependent on the geography of each one (Ivanov et al., 2016). Therefore, machines, devices, sensors, and people should be able to connect and communicate with each other via the Internet of Things (IoT) or the Internet of People (IoP). This is the expected meaning of interoperability (Karan & Irizarry, 2015), when applied to the AEC sector. Moreover, there is a strong synergy between these requirements and the technological infrastructure for a VBE (Afsarmanesh et al., 2009), in such a way that this platform might arise almost naturally, if production follows an Industry 4.0 approach (Ivanov et al., 2016).

Trends of the technological infrastructure and impact on sustainability

Industry development, despite important in economic terms, has originated growing problems, such as depletion of natural resources, negative impacts of waste and social damage. Industry uses 37% of the total amount of energy consumed in the world (EEA, 2010; IEA, 2013), which stresses the need to avoid waste during the total product lifecycle. There is an opportunity to increase energy efficiency and to improve the effectiveness of monitoring and management of energy (Wong & Zhou, 2015).

The ornamental stones cluster is very sensitive to the problem having promoted studies to refurbish machinery in order to reduce the consumptions of water and energy, at the same time that the production performance ratios are increasing. Reducing dust, waste and noise have also been recurrent concerns (Silva, 2014).

Industry 4.0 enables an opportunity for more sustainable value creation (Mosterman & Zander, 2015) since the resource allocation, i.e. raw materials, energy and water might be more efficient (Kagermann et al., 2013), contributing to the three dimensions of sustainability, i.e. economic, social and environmental (Veludo, 2015).

On the other hand, the real time approach to phenomenon of the Internet of Things (IoT) (Albert, 2015) facilitates object (inter)communication, i.e. information exchange about location, functionalities and problems enabling a strong connection with the virtual world by powerful sensing of the real world (Motamedi et al., 2016). The ability to monitor and control in real time the production of ornamental stones is essential to generate a positive impact on the environment. In this way, one may speak about closing the planning loop previously opened with the definition of the ecological footprint of the BIM objects with this ability to control the events in real time in the construction elements and, also, within the building itself (Wong & Zhou, 2015).

Moreover, as an "intelligent connection of people, processes, data and things" (Hoske, 2015), the IoT can improve the sustainability performance of the companies, since it magnifies the potential of the analysis in real time of several business processes and enables the visualization of resource inefficiencies (Benkhelifa et al., 2014). On top of that the growing availability of data through the IoT will bring a massive amount of information about the contexts where sensors are. Thus, by combining big data analysis, companies may identify with more accuracy environmental risks and even avoid resources to be fully depleted (Bojanova et al., 2015).

Evolution of purpose and relationships in value networks: a Service-Dominant Logic

The Service-Dominant Logic (Lusch et al., 2009) has developed by focusing its analysis on partnerships, relationships and value created, in alternative to production and product transactions. All the economic activity is understood as a service, and this, as a resource or competence of the value chain that exist and is available to benefit another entity (Lusch et al., 2009). So, services are the fundamental processes of the economic activity. As regards demand and supply of services stakeholders are understood as resources from the value chain of which the customer is part as a co-creator, always not fully satisfied (Payne et al., 2007; Lusch et al., 2009).

In the context of this assignment the targeted collaborative operations model is aiming at diversity, originality, differentiation, competitive price, short lead time, sustainability, safety and low maintenance costs, features that appear to be compatible with the value approach promoted by the S-D logic (Lusch et al., 2009). Moreover, the Service-Dominant logic is in line with BIM, as regards considering the customer as a co-creator, which is the architect role (Yalcinkaya & Singh, 2015). However, Ivanov et al. (2016) state that in smart factories it is not enough that IT just give support to services to distribute information within the value network as Lusch et al. (2009) put it. In fact, products should communicate with the machines inside the CPS, during the production process, independently of the plant location (Lasi et al., 2014; Davies, 2015). Therefore, the S-D logic fits a VBE because Innovation and Production supported by CPS might be seen as a service, since the architect (BIM modeller) might co-create innovation (Edvardsson & Tronvoll, 2013) and, then, send the final fingerprint to the plants' CPS exactly in the same way one sends a file to a 3D printer. On the other hand, the S-D logic does not consider communication processes between machines and customers, which is a drawback that limits the concept of Industry 4.0.

Considering the customer as part of the value chain within the VBE might be an advantage to the application of the VBE model (Romero & Molina 2010) to the ornamental stones cluster. In fact, the customer plays a significant role as value co-creator within the supply chain (Eppler, 2008) by performing the modeller job in BIM. Moreover, this solution might even be stronger by considering the *lean thinking* (Fullerton et al., 2014) and digital processes coming from the 4th Industrial Revolution (Mosterman & Zander, 2015). In summary, these concepts and theories are common to the AEC stakeholders and, therefore, they are identified as critical determinants of the mandatory objectives for BIM projects (HM Government, 2015).

Conceptual outline of the organisational model under development

In digital production there is a need for a perfect communication in real time between machines and customers, where lacking a *bit* might stop a full production line. Thus, some authors that have started from the S-D logic suggested a computer science approach, creating the service system concept, as configurations of co-creation of value by sharing information and, internal and external linkages of people, technology and organisations (e.g. Maglio & Spohrer, 2008; Edvardsson & Tronvoll, 2013). In the extreme, the global economy is the biggest service system, including cities, countries, governments and economic agents, such as companies and consumers (Maglio et al., 2009). The Service Science is the study of the service systems that are simultaneously supplier and customer of the same chain of services and, also, of co-creation of both value and innovation (Maglio & Spohrer, 2008). In *Service Science*, resource typologies of the value chain are identified according to their nature, i.e. resources with rights (people and organisations), resources with property (technologies and shared information) and, social resources (organisations and shared information) (Maglio & Spohrer 2008). These four categories are simultaneously centred on value creation by the S-D logic, where the customer is a co-creating resource in the supply chain and, in line with the principle of utilization of the BIM collaborative platforms (Yalcinkaya & Singh, 2015).

As regards the VBE model applied to the ornamental stones, advantages might arise from the service logic, i.e. from the interaction of the customer (BIM modeller) with the suppliers of objects within the AEC supply chain, which also is a source for collaborative innovation, both incremental and radical. By taking the Service Science view, the existing separation between products and services in the VBE models (e.g. Romero & Molina, 2010) might have to be reformulated under the grounds of the 4th Industrial Revolution (Constantinescu et al., 2014). Moreover, the customer might have to be considered as an internal resource able to co-create value and innovation within the VBE. In addition to the Service Science, the conceptual VBE model for the ornamental stones should be part of the current paradigm and include emerging ideas such as the *Internet of Things* and the *Industry 4.0*. This is a strong modern despite arguable view to converge over the mandatory objectives set to drive the BIM approach (HM Government, 2013).

In summary, it is proposed that the suppliers of products in stone (plants) might be considered as an interactive resource of the customer (BIM modeller). Thus, he or she will co-create innovation when integrating the value chain. This innovation will be sent as a final fingerprint, in IFC format, to the plants CPS. Thus, the BIM modeller and the supplier interact to optimize the final product. This simplifies the ICT typology essential to a VBE (Afsarmanesh et al., 2009).

5. Conclusions

This research made an attempt to outline the main guidelines for an innovative business model adequate to the ornamental stones Industry that targets excellence in the global market. The exploratory research questions were established inductively, based on the cluster observation put in the competitive context. They anticipated the Industry purpose and so, a proposal for a collaborative network model with two critical dimensions, i.e. the organizational and the ICT infrastructure. The *ex-post* discussion helped to theoretically assess the interest and adequateness of the proposal and to characterize the guideline requirements of this model by following the Service Science logic leveraged by state-of-the-art digital technologies such as

BIM, Internet-of-Things and Industry 4.0. This was the chosen path to operationalize a value system based on a collaborative network attempting to match the requirements for the cluster strategic positioning.

Revisiting the research questions

As regards collaborative typologies (RQ1), the VBE/VO operations model appears to fit well within the "mandatory" dimensions of the competitive context of the ornamental stones, by assuring the sustainability of Portuguese familiar SME within the environment of the AEC sector. In fact, the co-creative collaborative interaction between the BIM modeller (customer) and the resources (suppliers) was understood as a cornerstone in value creation centered on a service dominant logic.

As concerns the specification outline of a collaborative network (RQ2) inter-organisational systems that respect common interoperability protocols should be outlined for the AEC sector by considering a strong synergy between organisational requirements and the technological infrastructure for a VBE. Digital technologies, such as Industry 4.0 and Internet of Things should support the creation of Cyber-Physical Systems where real and virtual worlds meet to operationalize a competitive and sustainable Service System.

These concepts and theories, which are already available to the AEC stakeholders, are identified as critical determinants of the mandatory objectives for BIM projects as follows: reduction in the costs of construction, in the costs of maintenance, in the construction time and in the total CO_2 emissions, in the construction industry. The Portuguese ornamental stones cluster aims at developing a leading industry, under a World Class Manufacturing paradigm (RQ3).

As regards the methodological options (RQ4), the ECOLEAD Reference Model was chosen to represent a collaborative network. The approach should start by a general VBE/VO model completed by knowledge coming from BIM, Industry 4.0 and Service Science backgrounds, in order to build up a specific model to the ornamental stones Industry. Finally, the specific model should be verified by a case study as a demonstrating instance.

Expected innovative contributions

This research assignment should contribute to an innovative approach to the (re)organization of an important sector to the country – the ornamental stones Industry. This approach is closely related to the development of organizational environments to incubate and source virtual organisations. The scope of the investigation concerns both the organizational and the digital (ex-ICT) dimensions of the model. The following contributions are expected:

1. To theory, as regards the development of the stage I of the reference model, which focus on the broad business needs; this model is enough general to be customized to other domains, if its usability and applicability requirements are fulfilled;

2. To research in the Operations Management domain, as concerns the positioning of operations as the thrust of value co-creation and as supporting the achievement of competitive advantage (stage IV of Hayes & Wheelwright); the stage II of the reference

model is expected to generate a model specific to operations in the domain of ornamental stones, in Portugal;

3. To practice, because the research should drive the modernization of the ornamental stones Industry, assuring its survival even in global hostile competitive environments; the development of organizational models enabling economies of scale and scope should be facilitated and verified through case studies (stage III of the reference model).

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Digital Global Value Chains and the alternative upgrading path: innovation with end-user

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Abstract

There is a considerable volume of knowledge already accumulated in the area of consumers' influence upon the evolution of global value chains. In seeking to advance that process, this article aims to identify the determinants that enable the relationship suppliers-consumers to become a key factor for supplier's upgrading in the digital games value chain, which is a privileged field for research in that area. The Global Value Chains approach is applied to establish the analytical framework for the study.

Keywords: Global Value Chains, Upgrading, End-user innovation, governance, digital supply chains.

1. Introduction

This article suggests that innovation efforts with end-user innovation allow alternative routes of upgrading in digital chains. This fact happens due to a few reasons. First, digital industries present direct communication channels between the supplier and the end customer (NABISAN; NABISAN, 2008; ROBERTS, HUGHES, KERTBO, 2014). Second, digital industry is a fast-changing environment (FINE, 1998; GRANTHAM; KAPLINSKY, 2005; READMAN, GRANTHAM, 2006; GRAFT 2016). As a consequence, end-users are relevant partners in the different phases of product development (NAMBISAN 2002; PRAHALAD; RAMASWAMY, 2004a and 2004b; NAMBISAN; NAMBISAN, 2008; SAWHNEY; VERONA; PRANDELLI, 2005). Nambisan, an important author in the field, states that "consumers can be involved not only in generating ideas for new products, but also in the co-creation of these by testing products and providing support" (NAMBISAN, 2002).

The literature on Global Value Chains (GVC) has helped scholars and practitioners to understand the dynamics and organization of global industries and to explore how different companies relate to deliver goods and services to the end user (GEREFFI, FERNANDES-STARK, 2011). Two key aspects of this literature are the governance of the chain and the upgrading (GEREFFI; HUMPHREY; STURGEON, 2005; PONTE; EWERT, 2009). Because GVC literature has its roots in the study of traditional industries and how developed country firms coordinate a geographically dispersed supply base (GEREFFI; HUMPHREY; STURGEON, 2005) is natural to note that both the governance and the upgrading has been discussed the under the point of view of the firms that lead the chain.

On the one hand, the governance discussion in value chains has been based on the seminal typology developed by Gereffi, Humphrey and Sturgeon (2005). Depending on the characteristics of the transactions between the leader of the chain and its suppliers, different coordination models may exist. On the other hand, the term upgrading summarizes the different opportunities that a supplier has to develop skills and balance the power asymmetry within the chain (KAPLINSKI; FAROOKI; 2011; HUMPHREY, SCHMITZ, 2002). .

By focusing on the relationship between the leader of the chain and its suppliers, with a focus on the role of the leader, GVC literature does not analyze the possibility that suppliers seek opportunities of upgrading without interference of the chain leader - and possibly outside leader´s interest. This assumption is fairly valid in traditional industries, which presents well defined flow of materials and information. However, in modern digital industries, the flows of products and information are not linear and the end user is a potential collaborative partner for companies that are at the bottom of the value chain, such as developers of digital products (ROBERTS, HUGHES, KERTBO, 2014; NAMBISAN; BARON, 2009; NAMBISAN 2002). For instance, in the electronic games industry, game developers receive information not only from the chain leader but also from end users; in other words, suppliers within digital GVC benefit from knowledge and "inputs" from final consumers (CADIN; GUÉRIN, 2006; FULLER; MATZLER, 2007; SAWNEY, VERONA, PRANDELI, 2005; PAYNE, STORBACKA; FROW, 2008; GIDHAGEN; RIDELL; SORHAMMAR, 2011).

Because the GVC literature does not discuss the possibility of upgrading of a supplier without interference of the chain leader but the literature about innovation with end-user supports the existence of some types of upgrading of suppliers, this article seeks to identify the conditions required from the innovation with end-users to provide an alternative upgrading path in the digital industry (SINGH, POWER, 2009; BRADLEY; MEYER, GAO, 2006). Our goal is to debate whether the interaction between the end-user and supplier (at the bottom of a value chain) allows product, functional, process and interchain upgrading. Thus, the research question to be answered is therefore: ***Under what conditions innovation with the end-user becomes an alternative upgrading path to a supplier in a value chain.*** This question is easily answered in traditional industries, such as in the automotive industry in which suppliers of parts, do not receive direct input from end users.

2. Global Value Chains

2.1 Chain types versus upgrading possibilities

The literature on GVC recognizes that the type of governance impacts upgrading opportunities of the suppliers for companies that participate in the chain (HUMPHREY; SCHMITZ, 2002; PIETROBELLI; RABELLOTTI, 2011; SCHMITZ, 2004; MORRISON; PIETROBELLI; RABELLOTTI, 2008).

Suppliers in Modular chains work within a context of strict technical specifications (PIETROBELLI; RABELLOTTI, 2011) and provide modules to their customers according to their specifications (GEREFFI; HUMPHREY; STURGEON, 2005; PIETROBELLI; RABELLOTTI, 2011), while in Captive chains leaders have more impact on their suppliers, which are limited to run specific set of tasks. In order to mitigate risks, the governing firms develops skills of its suppliers (GEREFFI; HUMPHREY; STURGEON, 2005), which leads to product enhancements and processes. However, the same chain leader discourages the development of skills that may threaten the leadership of the GVC (SCHMITZ, 2004; PIETROBELLI; RABELLOTTI, 2011).

Finally, long-term relationships occur in relational chains because of mutual dependence (GEREFFI; HUMPHREY; STURGEON, 2005). In addition, the informal nature of these relationships enable the transmission of information and tacit knowledge (PIETROBELLI; RABELLOTTI, 2011), which can promote more sophisticated ways of upgrading.

As a consequence, all governance models present a link between the possibility of upgrading of the supplier and the involvement of the chain leader. However, up to this point the GVC literature implicitly supports that upgrading of a supplier depends on the chain governor. The next topic shows that the GVC model has shortcomings because it ignores that there are upgrading opportunities through sources external to the chain and one of those is the interface between supplier and end-users.

2.2 Criticism of the GVC framework and improvement of the model.

As seen in section 2.3, upgrading is the movement that leads companies to productive activities with higher added value through improvement of technology and knowledge (BARRIENTOS, GEREFFI, ROSSI, 2011) and acquisition of skills associated with more sophisticated activities. As firms obtain new skills they assume positions that add more value in global chains (GEREFFI, 2005). Thus, the concept of upgrading is intrinsically linked to acquisition of skills. However, the literature on GVC has a bias because it gives the chain leader the priority, or leadership, to say the least, in the acquisitions of skills acquisition of its suppliers. This bias explains why, as explained by Bair (2005) and Neilson, Pritchard and Yeung (2014), governance literature was developed with a focus on buyer-driven chains.

Different governance patterns may encourage or discourage upgrading, as synthesized by Morrison, Pietrobelli and Rabellotti (2006); however, these authors argue that the GVC literature ignores not only the efforts of suppliers to obtain more knowledge by themselves but also the learning opportunities that exist outside the value chain. According to these researches, the theoretical agenda of GVC should focus not only on learning processes within the chain, but also the mechanisms that allow flow of knowledge, especially those between different value chains. (NAVAS-ALEMAN; 2011)

The bias of the GVC literature can be challenged on the basis of several authors, some very recent, that discuss the learning opportunities of suppliers**.**

- The analysis of global value chains of traditional industries (ALBORS-GARRIGOS; MOLINA; MOLINA, 2014) shows that many players outside the chain contribute to technological innovation (or upgrading, according to the GVC vocabulary). Thus, the position of the authors contrasts with classic thinking of the GVC analysis, which advocates that the possibility of upgrading is dependent on the chain leader. Such scholars support two claims: (i) GVC framework need to be expanded to incorporate external sources of improvement; (ii) such sources may be end-users, other firms within the chain, universities and external laboratories.
- According to Iddris, Awuah and Gebrekidan (2014), the cooperation with consumers via open innovation, facilitated by the use of tools such as "cloud computing", affects the agility of a supply chain (or process upgrading, in the GVC vocabulary). The authors suggest that external sources of information that may increase chain ability may be other firms (whether in the chain of not), end-users and large retailers.
- Billington and Davidson (2013), after analyzing the effects of open innovation in supply chains, identified that improvement opportunities exist both in internal processes and in product development (CHESBROUGH, 2003; CHESBROUGH, 2007; BILLINGTON; DAVIDSON, 2013).
- Cox (1999), after analyzing power relations in supply chains, reached the same conclusion without utilizing the concept of open innovation. The author offers the argument that interaction between firms and their end users fundamentally transforms the supply chains of firms.
- Schmitz (2007), in his article about the conditions that determine the transition from competences of production to competences of innovation, points out that is necessary to combine the GVC approach (which contributes to the understanding of links between firms) with the other that support external influences on the innovation process. According to the author, the innovation systems that favor local relationships are one of the mechanisms to acquire competences for innovation (SCHMITZ, 2007).

The conclusion from this discussion is that there are external sources of upgrading in the GVC. Therefore, this article seeks to fill this gap in the GVC literature.

The next step is to limit the problem to a restricted domain. Regarding the type of industry, this article will focus on the digital games industry because it possesses three important characteristics, namely: (i) is a non-traditional industry. (ii) is a solid example of a fast clock speed industry (FINE, 1998), (iii) allows some forms of external learning (CADIN; GUÉRIN, 2006; FULLER; MATZLER, 2007; SAWNEY; VERONA; PRANDELI, 2005; PAYNE; STORBACKA; FROW, 2007; GIDHAGEN; RIDELL; SORHAMMAR, 2011).

Another limit refers to the focus on the end-user as a source of knowledge for the supplier upgrading. Although Pietrobelli and Rabellotti (2011) have highlighted the importance of innovation systems and learning among firms in emerging markets, the debate proposed by these authors did not include collaboration with end user as a source of innovation, development of new products or improvement of processes.

The next chapter shows that innovation resulting from the interaction between companies and end users creates changes that refer to what the GVC literature calls upgrading.

3. Innovation with end-user

3.1 How this article positions itself relatively to the literatures on GVC and on Innovation

The literature on innovation with end-users (PRAHALAD; RAMASWAMY, 2004; NAMBISAN; NAMBISAN, 2008; SAWHNEY; VERONA; PRANDELLI, 2005; NAMBISAN; NABISAN, 2002; ROBERTS, HUGHES, KERTBO, 2014) discusses the possibility of value generation (or value co-creation, depending on the author) through the interface between supplier and end-user. This interaction (also called collaboration with end-user), leads to the discussion about the possibility of a change of logic of upgrading in value chains: while the "traditional logic" presents no possibility of upgrading without support from the chain leader, the "new logic" may allow upgrading from innovation generated from the interaction between a supplier in the bottom of a chain and its end-user.

Von Hippel (1998) supports that there are four sources of innovation: the firm, the end-user (or consumer), suppliers and third parties (eg universities). Therefore, this article will focus on one of these sources, the end-users, and will discuss the possibility of end-users provide an alternative path of upgrading.

The academic literature shows that the role of innovation with the end-user in the generation of new products has been relatively well explored (CHRISTENSEN, 1997; von HIPPEL 1988), although the importance of the consumer in the conceptualisation of new products varies with the maturity of technology (CHRISTENSEN, 1997; LEONARD-BARTON, 1995).

The increasing involvement of users in the creation of value with companies was also identified by Prahalad and Ramaswamy (2004a), who argue that the connection (in varying degrees) between the firm and the end-user in the activities of idea generation, development and creation of new products is a pre-requisite to innovation. The authors points out that there is a change in the system of value creation; initially it was focused on the company itself but the new value creation system advocates joint innovation between client and firm (PRAHALAD, RAMASWAMY; 2004a). In this new system, the client appears as co-responsible for creating value, developing (or helping to create) products that will adequately meet customer´s specific needs.

An important distinction that needs to be made is the one between innovation oriented to the customer and innovation with the customer. The differentiation occurs in the role of the consumer in relation to the development of new product or service. In one hand, in the case of innovation “with the customer”, the user assumes a passive role in the innovation created by the firm and is limited to answer what is asked by the firm, which will use the answers to generate market intelligence, will be translated into marketable products and services. On the other hand, innovation “with user the organization” use of techniques to integrate the users in the new product development process (LUTHJE; HERSTATT, 2004).

On the other hand, innovation with consumer is a specific form of deriving contribution from end-users, who adopts an active attitude to contribute with their inputs (knowledge, informed opinion, experience of use/consumption) in the innovation process of firms. (ROBERTS, HUGHES, KERTBO; 2014). It is important to note that even though the company did not lead the innovation process with the consumers, it can benefit from the interface with them (PRAHALAD; RAMASWAMY, 2004b).

Nambisan (2002) in his influential article on the roles of end consumers in the development of new product presents three possible consumer profiles in collaboration with firms: (i) resource for ideation, (ii) co-creator of development and design and, (iii) user-tester of solutions. However, Nambisan (2007) expanded its own typology to include a new collaborative profile: the technical support of products. As a consequence, this author suggests that collaboration between consumer and firm covers not only the development of new products but also includes product support (a service-oriented activity), dissemination of information (a marketing-oriented activity) and product improvement (a production-oriented activity) (NAMBISAN, 2007). This change presents the idea that collaboration with consumer can occur in several stages of product development process.

The role of users as innovation generators in these contexts has also been described in Tapscott and Williams (2007); who add that, in the digital age, the boundaries that separate the users to the producer are increasingly tenuous. The authors used the term “prosumer”, to identify products developed by consumers. The low cost of implementation of digital tools and the potential benefits of using the existing knowledge in this environment make innovation with user a promising sources of innovation for companies in current times (TAPSCOTT; WILLIAMS, 2007; DAHLANDER; GANN, 2010).

However, after identifying that consumers can support innovation with firms through various roles and along different stages of the innovation process, there is no answer to the following question: "What conditions are necessary for consumers to engage in innovation processes of firms?". The next topic will present the four conditions to be studied in this article: the motivation of consumers, the opportunities offered by the firms, the ability of consumers to contribute and the digital infrastructure.

3.2 Conditioners of innovation with end-users.

Literature on innovation offers studies showing that consumers participate in the innovation efforts with companies if some conditions are present. Aherarme, Bhattacharya e Gruen (2005), after studying digital communities of consumers, offers a model that examines key factors that drive exchange of information between end-users and firms; such model, the MOA (Motivation-Opportunity-Ability) framework, helps to understand the creation of value based on customer interactions amongst themselves and the firm. According to this model MOA (MACINNISs et al, 1995; JEPSON, CLARKE, RAGSDELL, 2013), the degree of participation of consumers in innovation activities with companies depends on three factors: motivation, opportunity and ability.

Thogersen (1995) not only used the same MOA model but also argued that the study of consumer behavior should not be limited to three variables M, O and A. This conclusion is useful to this article because it provides theoretical ground to the use of an additional conditioner: the digital infrastructure, which will be presented after the discussion of the MOA framework.

3.2.1 Motivation

MacInnis et al (1991 define motivation as a force that drives individuals to objectives and motivates them to engage in changing behaviors, in making decisions and in processing of information Therefore, what would be the main motivating factors for consumer to participate in innovation-related activities with businesses? For von Hippel, leading author in the field of innovation, the main motivational factor for users is the fulfilment of their needs (VON HIPPEL, 1986). From this definition we conclude that consumers become motivated because of their own need of better products and services. MacInnis et al (1991), after analyzing definitions of motivation show that motivation can be defined both by tangible characteristics such as consumer´s readiness to interact with companies and the frequency of such interactions occur and by intangible characteristics such as “will” or “desire”.

3.2.2 Opportunity

The opportunity is the second condition to allow interaction between the consumer and firms. While the first condition, is the force that drives user to cooperate in innovation efforts, the second condition, opportunity, is related to a situation in which such cooperation may might exist (MACINNIS et al; 1991).

Thogersen (1995) in their studies about consumer behavior, suggests that opportunity occurs with the implementation of the an act desired by the firm. The role of the firm which creates the opportunity is critical for the occurrence of joint innovation activity, a conclusion also presented by Van Ophem (1992).

3.2.3 Ability

The ability of a consumer to participate in joint innovation projects firms is another conditioner presented by MOA framework. According to MacInnis et al (1991), ability refers to skills and competences of the consumer about task. Therefore, to have high skill involves the possession of prior knowledge.

The use of the competences of consumers is not new in many industries; however, the notion that consumers are source of competence is more intense in technology and knowledge intensive industries such as software (PRAHALAD, RAMASWAMY, 2000).

3.2.4 The last conditioner: Infrastructure

If on one hand the MOA framework explains the conditioners to the engagement of consumers in innovation processes with companies, on the other hand the model does not address the necessary tools that allow cooperation between consumers and businesses. This deficiency is even more striking when one analyzes the collaboration between business and consumers in the digital games industry, given that this industry makes intense use of the digital infrastructure and tools to engage their consumers in various stages of development of new products (NAMBISAN, 2002). As a consequence, infrastructure must be considered a required conditioner in order to evaluate end-user innovation in digital industries. We present two examples of tools that condition the participation of users in innovation with firms in the digital industries.

a. Virtual communities as a conditioner for the consumer-supplier collaboration

The approaches that organizations use to obtain cooperation from consumers in the creation are changing rapidly, both in traditional industries such as education and automobiles and creative industries such as video games and social networks (PRAHALAD; KRISHNAN, 2008). Due to the development of technology and the rise of the internet, the development of virtual communities that allow collaboration between consumers and firms on product development has been the subject of many studies (SAARIJARVI: KANNAN, KUUSELA; 2013; SAWHNEY; VERONA; PRANDELLI, 2005; NAMBISAN; BARON, 2007; NAMBISAN; BARON, 2009; FULLER; MATZLER, 2007; BILGRAM; BREM; VOIGT, 2008). Because the internet is a highly-interactive technology, along with low cost of mass communication, it allows consumers to experience new products and offers simplified modes of interaction on a large scale between producers and consumers (FULLER; MATZLER 2007).

One kind of tool that companies use to attract and orchestrate the collaboration of end users our process of new product development and innovation is the creation of Virtual Consumer Environments (VCE). These environments, ranging from simple discussion groups to sophisticated prototyping environments, enable firms to involve users in the design, testing and support activities (NAMBISAN, 2002) and reverse the traditional "top-down" pattern of product development via experimentation and activism (PRAHALAD; RAMASWAMY, 2004B). Such virtual communities of consumers may provide support to products and services, promote brands and be a source of ideas (NAMBISAN; SAWHNEY, 2007; FULLER; MATZLER, 2007; NAMBISAN; BARON, 20010).

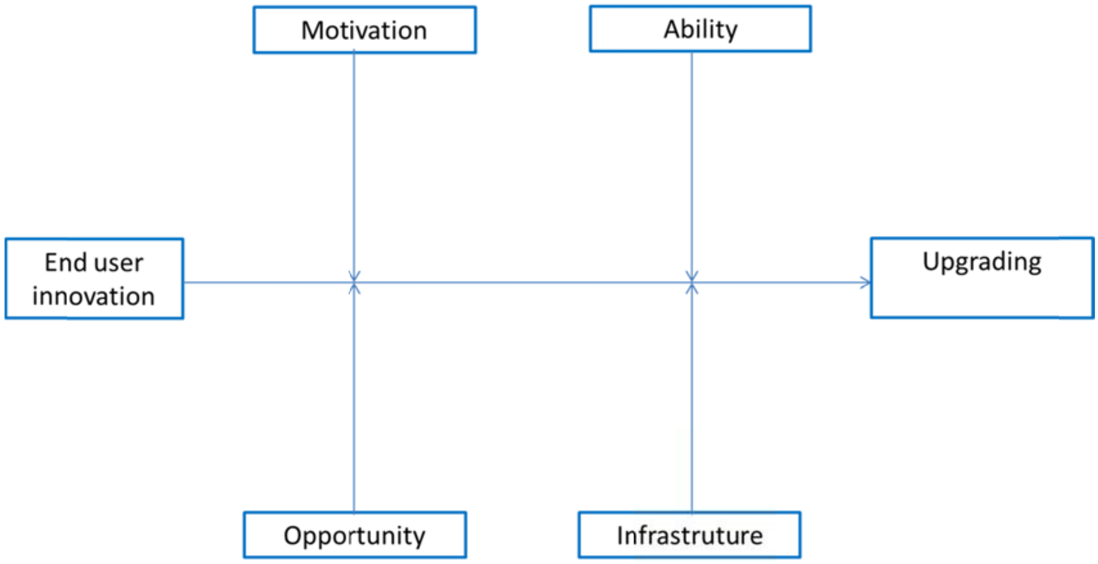
b. Toolkits as conditioners for the innovation with end-user

In addition to the use of VCE to allow innovation with end-customers, literature review presents that firms also use toolkits to support collaboration and knowledge transfer with end-users. (THOMKE; VON HIPPEL, 2002; VON HIPPEL, 1988; VON HIPPEL; KATZ, 2002), A user toolkit is tool that enable customers to developed customized product without having dedicated knowledge; therefore, toolkits are important part of the infrastructure that is required to accelerate user contributions to innovation. (PILLER, IHL, 2009).

3.3 Theoretical model: conditioners for an alternative upgrading path in digital GVC

After reviewing the literature about innovation with end-user, most remarkably in digital industries, this article suggests an alternative path to upgrading that is not foreseen by the traditional literature on GVC. However, as many authors have pointed out, there are some conditioners that are required to allow upgrading and the MOA framework and Infrastructure are candidates to be those conditioners. Therefore, the theoretical model is shown in Figure 2:

Figure 2: Theoretical model of conditioners for alternative upgrading path in digital GVC



3.4 Hypothesis to be tested in field research

The theoretical model allows the development of hypothesis to understand how the conditions for innovation with the end-users affect the upgrading opportunities of suppliers:

- Hypotheses #1: The motivation of end-user influences the upgrading of suppliers.
- Hypotheses #2: The opportunity offered by the supplier influences the upgrading of supplier.
- Hypotheses #3: The ability of users opportunity influence the upgrading of supplier.
- Hypotheses #4: The infrastructure offered by the supplier influence the upgrading of supplier.

3.5 Expected results

One of the results **expected** from the field research is that **different types of governance will lead to different levels of importance of each conditioner**. For instance, in Relational chains we expect that the conditioners that are closely linked to customers – Motivation and Ability – may be more relevant that the conditioners closely linked to suppliers – Opportunity and Infrastructure. Conversely, in Modular and Market chain the conditioners Opportunity and Infrastructure are expected to be more relevant than the remaining conditioners.

Research may drive different conclusions in respect to the type of digital game. Because mobile games tend to be less sophisticated than games for consoles, we expect that the conditioner Ability (of the end-user) may be more relevant in the console segment than in the mobile segment.

Finally, because idiosyncrasy of the digital game industry, we expect that the conditioner Infrastructure will show high levels of importance in all types of governance and in both segments mobile and console segments.

3.6 Theoretical Contribution

Once the validity of the propositions is achieved, this work will have answered the following research question: ***Under what conditions innovation with the end-user becomes an upgrading alternative supplier?*** Through evidence of the occurrence of upgrading not foreseen in the traditional GVC literature, this article contributes to the expansion of the theoretical knowledge about value chains because it will:

- Show that innovation with end-users provides an alternative path to upgrading independently of the chain leader
- Identify the influence of Motivation, Opportunity, Ability and Infrastructure on the upgrading of the supplier.
- Link the literatures about GVC and Innovation with end-users.

The next chapter will present the reasons that led to the choice of digital game industry as an analytical object of academic research

4. Digital Games Industry

4.1 Reasons for choosing the digital games industry as the object of analysis

The industry of digital games is important because of a series of factors such as its ability to generate employment and income (FLEURY; NAKANO, SAKUDA, 2014), its technological innovation (TOMASELLI; Di SERIO, OLIVEIRA; 2008; GRANTHAM; KAPLINSKY, 2005)), its hybrid profile between hardware and software (READMAN, GRANTHAM, 2006), its high level of interactions between end-user and firms (GIDHAGEN; RIDELL; SÖRHAMMAR, 2011; NAMBISAN, 2002, NAMBISAN 2007, NAMBISAN 2008, NAMBISAN 2009) and its interconnection with other industries such as music, sports, entertainment, film, technology, hardware and software (JOHNS, 2006; FLEURY, NAKANO, SAKUDA, 2014).

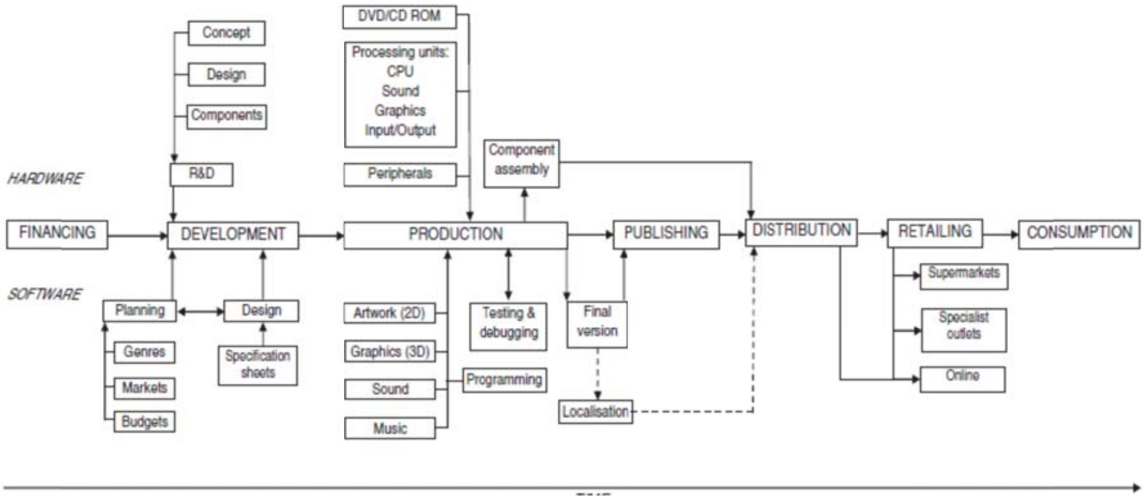
Another important feature of the digital game industry is its global profile, given that the game developers are located in several countries and their activities are controlled by global corporations (READMAN; GRANTHAM, 2006).

Finally, the digital games industry is a fast clock speed industry because it presents increasingly shorter and intense cycles (JOHNS, 2006). According to Fine (1998), the study of companies with high rates of evolution allows learning that could only be obtained after long periods of observation in traditional industries (FINE 1998).

4.2 Overview of the industry of digital games

Johns (2006) introduces the complexity of the industry of digital game after showing that this segment is based on two interrelated industries, the hardware manufacturing and the software development. Additionally, the analysis presents the integration between the game industry with other industries such as music and film (JOHNS, 2006). Finally, this industry is based on several steps ranging from the funding of the product until its deliver to the consumers. Figure 3 shows the activities necessary in the stages of development of the games.

Figure 3 - Video game production steps



4.3 Adequacy of the digital games industry to analyze the impact of collaboration between end users and developers in the digital GVC

The digital game industry has been an important field of study for the discussion on collaboration between end-users and firms. The impact of this relationship on firms of this segment has been vastly studied by several researchers such as Cadin and Guérin (2006), Jeppesen and Molin (2003), Nambisan (2002), Nambisan and Baron (2007), Prahalad and Ramaswamy (2004). Therefore, the game industry is suited to test the hypothesis presented in the previous topics chapter and to validate the proposed theoretical model due to the following reasons:

a. Presents many collaborative communities between digital firms and the end-users (NAMBISAN, 2008; ROBERTS, HUGHES, KERTBO, 2014).

b. Uses consumers as a source of innovation, either in products or in services (GREER, LEI, 2012).

c. Is an industry that possesses dynamic nature (FINE, 1998). In this type of segment changes happen rapidly, which attracts research due to short cycle times

d. Promotes technological innovation (GRANTHAM; KAPLINSKY, 2005; JOHNS, 2006).

On the one hand, the existence of studies of online communities of users participating in the improvement of digital games (SAWHNEY; VERONA; PRANDELLI, 2005, NAMBISAN, BARON, 2007) provides additional strength to the argument that the collaboration between developers and users finals has been an important tool in the development of new products in the digital games industry. According to Jeppesen and Molin (2003), the gaming industry for computers was one of the first to emphasize the collaboration with customers.

A key piece of evidence on the impact of interface with game users and industry is offered by Cadin and Guérin (2006), who claim that current games are the result of collaborative processes in which users contribute to the evolution of the game, a situation that contrasts with the first products offered to the market, which were exclusively fruit of firm´s efforts (CADIN; GUÉRIN, 2006).

An outstanding example of innvation with end-users and firms that develop digital games is the Half-File, science fiction first person shooter game which became the best-seller game in history. At one point, one of the users who also coordinated a community of players perfected the game through a development kit provided by own studio that developed the game. While the original game was played individually, the new version allowed several players to play online simultaneously. The modified version, Counter Strike, exceeded the original in popularity. Currently, the game is a separate product and is among the ten best-sellers of the digital game history (GIDHAGEN; RIDELL; SÖRHAMMAR, 2011). Therefore, Counter Strike is what in the GVC literature calls product upgrading; however, this upgrading initiative happened without involvement of the leader of the digital value chain.

Finally, the use of online user communities is further evidence of the suitability of the digital game industry as an object of study on cooperation between firms and users. When developers share games with consumers, they discover and debug, test the product, identify problems and offer suggestions (GIDHAGEN; RIDELL; SÖRHAMMAR, 2011; BURGER-HELMECHEN, COHENDET, 2011).

4.4 Further research

This article suggests that the Motivation, Opportunity, Ability and Infrastructure are the conditioners to upgrading in digital global value chains. However, field work is required to prove this claim. Therefore, the next steps for this research should include the measurement of each of conditioner. Literature review must be the source of the benchmark for each conditioners. For instance, Table 4 presents preliminary analysis undertaken so far

Table 4: measurements for each conditioner

Conditioner	**Measurement**	**Literature review**
Motivation	• Responsiveness of user • Frequency of participation of users	MacInnis et al (1991),
Opportunity	• Disponibilization of internal teams	Van Ophem (1992) Olander and Thogersen (1995),
Ability	• Skills in digital games • Technical knowledge about codes	(Prahalad, Ramaswamy, 2000)
Infrastructure	• toolkits • discussion forums	Franke; Piller, 2004; on Hippel; Katz, 2002;

		Thomke, von Hippel 2002

Further analysis is required to understand the relative impact of each conditioner. More specifically, quantitative research will be necessary to evaluate if each conditioner impacts differently the upgrading of game developers.

Finally, the idea of upgrading is more complex than the one presented in the model in figure 2. As shown previously, there are four modes of upgrading and the conditioners may impacto ne or another. Field research not covered in this paper should provide the answer.

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Sustainable manufacturing: steps for leading organisational change

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Abstract
Environmental and social pressures are increasingly featuring alongside economic pressures on companies to improve. Manufacturing companies in particular are under pressure to reduce the negative environmental and social impact of their operations and leading companies are seeking to create positive environmental and social impacts. Capturing the characteristics of how leading companies undertake organisational change to control these impacts could offer opportunities for other companies to start or accelerate their own change. This paper documents research carried out with companies known for their leadership in the area of sustainable manufacturing. The case data collected was analysed and seven key steps were identified: vision, leadership, education, simplicity, pilot, momentum and broadcast. The steps are detailed and opportunities for future research are discussed.

Keywords: sustainable manufacturing, organisational change, leadership

Progressing change towards sustainable manufacturing
Sustainability (WCED, 1987) as a concept that integrates economic activity with environmental protection for social good is acknowledged by many companies through sustainability policies, staff appointments and activities to reduce operational impact. Accepting that companies alone cannot be sustainable, there has been significant activity in developing socially responsible strategies combined with environmental impact reduction projects (Kleindofer et al., 2005; Garetti & Taisch, 2012). Such activities can act as enablers for supply chains and wider industrial eco-system to progress towards sustainability. Ultimately the language could change from reducing impact to eliminating harm (Montabon et al., 2016) to enhancing impact, or as Ehrenfeld (2008) argues, flourishing.

In order to make progress towards sustainability, companies must initiate and maintain activity just in the same way that lean production (Womack and Jones, 2005) is a continuous journey. So how do companies initiate and maintain activity? We know that for lean production replicating others' tools and methods is insufficient to initiate and sustain improvements (Drew et al., 2004) and that understanding how processes are incorporated within an organisation is important (Mejías et al., 2016). So, is the process different from particular endeavours such as lean production or more general change management? A lot has been published on the technical achievements of companies from specific practices to more general performance improvements (e.g. Hajmohammed et al., 2013; King & Lenox, 2001; Zhu et al., 2004) as well as on how to progress sustainability strategically at the firm level (e.g. Bansal & Roth, 2000; Montabon et al., 2016; Moretto et al., 2016). However, there remains a gap in understanding how the programmes of change are started, expanded and sustained.

Much has been published on what is required to support significant change within the area of leadership (Fullan, 2004) and leadership and sustainability (Doppelt, 2003; Avery & Bersteiner, 2011). There is significant insight to qualities of individual leaders (Waldman et al., 2006; Visser & Courtice, 2011; Knight, 2014), the need for vision, people development and performance management (Avery & Bergsteiner, 2011) and the need to tackle the complexity of systems (Fullan, 2004). What does not feature so strongly is the overall journey that the organisation takes under this leadership and how companies progress from small beginnings, ramp up the rate of change and move to an era of maturity and engage in experimentation as would be seen in lean journeys.

There is significant work on the principles for organisational change and initiation of that change. Senge et al. (2010) consider both leadership and the transformation of companies, in particular about how to engage others and see challenges from different perspectives. Others examine the process to follow for change (e.g. Herrmann and Thiede, 2009; Smith and Ball, 2012), the barriers to change (Lunt et al., 2014; May et al., 2016) and the relationship with investments (e.g. Klassen, 2000). What is absent is how the environmental change propagates from a pilot area to the wider company and beyond and the level of caution companies take to both the technical changes as well as the communication of success.

This paper documents research that sought to ascertain what companies do to initiate and accelerate their sustainable manufacturing journey. Of interest is how others are engaged and supported in the growth of activity. The paper is structured as follows: first the research design justifies and details the approach used; next the case data is presented, clustered and categorised into a collection of steps; finally the findings are discussed and conclusions given.

Research design

The research was motivated by early literature review that revealed a lack of insight into how organisations go about leading change towards “more sustainable” (less unsustainable) pathways. In particular, operationally what are companies doing in making tangible changes at scale beyond high profile technological implementations. The overall aim was to uncover the steps that companies take to initiate and accelerate their sustainable manufacturing journey.

Familiarisation with and reflection on (Easterby-Smith et al., 2012) research and practice through literature and discussion triggered the focus on the steps for leading a sustainable manufacturing journey. Prior discussion with leaders in field suggested there could be commonality in their approaches. A decision was taken to use practitioners as the initial source of development using a grounded method (Glaser & Strauss, 1999) from early attempts to conceptualise the area rather than use the common approach of developing a conceptual framework from literature and then testing through case or survey.

Leaders for interview were selected out of purpose (Robson, 2011) and relevance of those available within a network of known leading companies to gain insight to the focus area. The prompt questions prepared were: What was the programme called? What was the trigger to start? What was the motivation to pursue long term? Who was involved, how was involvement achieved? Who supported? Where does the inspiration come from? What are the top tips to help others? The questions were to prompt description and were intended not to be leading on process steps. The interview stopped when the prompt questions were directly or indirectly answered and the interviewee volunteered no further insight. Interviews were carried out with known contacts by telephone lasting around one hour over one or two calls. Initial guidance was given to the interviewees to prompt the accounts of their/their companies' approach and continuous notes were taken of their accounts without audio recording or transcription. Later, clarifications were sought on the points made and feedback was gained on initial write-ups of the company journeys.

Coding of the interview notes was carried out to identify distinct features of the journey. The coding sequence aligned to open, axial and selective coding (Easterby-Smith et al., 2012; Robson, 2011). The coding was open and fluid and did not use pre-conceived codes. As the richness of the detail of the cases individually and collectively emerged, some of the codes were refined to better identify the particular feature of a journey. These codes are shown in italics in the case accounts in the next section. Through an iterative process, codes were clustered to form categories as connections were made between codes within a case and across cases. These categories were identified as major 'steps' in leading the sustainable manufacturing journey and Table 1 later shows those steps and their associated codes. Note that for Table 1, the clusters of codes are shown on the right of the table for ease of illustration rather than implying steps were created first and codes later matched to them. Finally, the codes were generalised across the cases for each of the steps to form 'aspects'. An aspect describes a generalised feature of a journey step drawn from multiple like codes. A decision was made to label the features as aspects rather than sub-steps as not all the features were displayed by each company, hence not all features need to be present to lead the sustainable manufacturing journey. Table 2 later shows the steps and associated aspects.

The development of the major steps presents how to lead operational progress towards sustainable manufacturing from initiation to on-going significant change. It is accepted that any approach developed by a company is iterative and not hierarchical, hence the sequence of steps indicates phases of activity rather than a strict linear sequence. The outcome of developing these steps was compared to sustainability and related literature. The next section details the cases with initial coding of the cases.

How leading companies approach change
Three accounts of the way companies progressed are detailed here. The significant features within each of their journeys are coded in *italics*. These codes were then clustered to distil the key steps with associated aspects in the next section.

Case 1 – automotive
This case company had a global footprint and designated a small number of *pilot plants* to lead the initiatives for the *sustainability vision* and *cascaded advances* to the rest of the companies. It accepted that its *vision* was distant to create *ambition* on how to reach the end point. They used the *journey metaphor* of seeing the end point without necessarily knowing the intermediate steps. The *vision* was one that staff could *believe* they can achieve but vague enough that everyone can *connect to*. Deliberately, whilst being *sensitive to local conditions*, they used *consistent messages* throughout the organisational hierarchy.

The value of *leaders* was given, explaining how they would *share knowledge* on the 'what' and particularly on the '*how*'. The company emphasised the *simplicity of its approach* and the need to always *go and see* (genchi genbutsu) the challenges at first hand in the workplace (gemba). In particular, it was important to *understand the basics* and why the current process was the way it was.

The company used its *philosophy of zero* waste for the *underpinning principles* for the journey towards sustainable manufacture and to live *in harmony with nature*. The company had a deeply held *belief* it needed to *minimise impact*. *Rules for simple processes* were developed and *communicated* to enable *local relevance* and fit with the *overall philosophy*.

Staff focused on what was behind the *fundamental impacts* on the environment and took many *incremental steps* and *proceeded cautiously* but *persistently*. The company valued consistent *long term evolution* of practice through *small steps*, each of which could allow *return to known condition* and start again if needed. By *encouraging trying* using *standard processes* then *mistakes could be permitted* a controlled way. A key lesson here was to *educate staff on why*. *Trials were performed* to understand the best way forward. Some of the work had *central funding* to remove risk from operations and *avoid barriers* to progress.

Significantly, *few full time staff* were responsible for the developments as a full-time role so they *engaged others* to *increase activity* and gave them the *reward* and *recognition*. These staff were considered to be the *champions* who would *cascade awareness* and *win hearts and minds* across the shop floor.

Case 2 – aerospace

This case company had a European footprint with a number of plants that were engaged in energy efficiency programme developed by a *pilot plant*. The company had an *ambitious vision* to *reduce energy and carbon*. *Successful initial projects* helped *generate confidence* for more projects. The company used *external funding* to start the energy reduction activity that involved *industrial and academic collaboration*. The initial activities justified the creation of an energy efficiency *network to develop the momentum* of change.

The company used a *network to cascade* the *standard way of working* that needed to balance *promoting quick wins* with *supporting disruptive projects*. The network used *local champions* who were *nominated by each plant* to *communicate clear practices*. The *support from the seniors* was recognised as important, however, the *motivation for change* came from the shop floor *improvement groups*.

Many staff were trained in the *standard process* and emphasis was placed on *questioning the fundamentals* by constantly *asking why* to avoid jumping to conclusions on solutions. The training sought to *provide tools* to *help others carry out their own projects* but *avoiding dictating detail*.

The company *adopted a standard process* from another company and *tailored it to their needs*. It used *inspiration from others* to *understand what works locally* having recognised its lean production success was by avoiding 'copy and paste' of standard methods. Their tailored process was *based on principles* of the waste hierarchy. They wanted to *deploy the approach widely* and recognised they needed to *avoid local inertia* from a 'not invented here attitude'.

They recognised that *'mundane' changes* that were *widely adopted* could be more effective than 'shiny' technology projects hence there was significant attention by the leaders to *change behaviours*. The local *successes enabled expansion* as *success was recognised*. Groups were keen to *learn from one another* and *understand why* some areas had better performance. It was realised that the approach had to *fit with the existing performance* measurement system. The *internal benchmarking* developed into *external benchmarking* as well as *working with suppliers*. Significantly the *network of champions* wanted to *celebrate success*, *foster enthusiasm in other staff* and find *time to have fun*.

Case 3 – food and drink

This case company has a small number of plants in the UK and with *initial motivation* driven by the *desire to reduce* their energy consumption under their *mantra of practical sustainability*. Their *initial successes* led to *wider understanding* of their carbon footprint and in turn resulted in them *working with suppliers*. Their overall approach was *simple and effective engagement* with a *practical mind-set* and *desire to demystify*. The company sees its *inspiration* come from *discussion and understanding* with the staff on what will *help others*.

Initial progress was challenging due to the *lack of information* and resulted in them *adopting standard methods* for assessment and *fast-tracking analysis* to *identify hotspots* in the business. News of their activities attracted *interest from others* including new and existing customers. The company needed to *engage others* and *avoid lack of interest* and *avoid defensive practices*. Their offer of *sharing tools and data* with suppliers was *initially resisted* as it was *perceived as a threat* but moved to *collaboration with suppliers* within a couple of years so that the *benefits were mutual*. They wanted to *help others* and *remove any fear* in calculations by *focusing on hotspots* and *not demanding accuracy*. In *helping others* they *helped themselves*. The *emphasis on simplicity* meant that assessment of carbon footprint *across the supply chain* was *matched to the data suppliers had available*, recognising their *suppliers did not have the time and skills to obtain data* demanded by sophisticated tools. The company later *worked with customers* to *help their customers* calculate the carbon impact. This was seen as *triple win* through driving lower cost, premium pricing and lower carbon footprint.

Within the company *staff were surveyed* and results showed a majority of *staff were aligned* to the *sustainability vision* meaning that the *advances come from all staff* and *not the responsibility of one lone leader*. There was *emphasis on the practical and basic* aspects and *using the information available*. The view was to do the *basics first*, get *clever afterwards*. They were *not interested in offsets*, etc. Having worked on the basics for many years their next big thing was *investing in technology* for renewable energy.

Steps for leading organisation change

The cases presented in the previous section summarise the journeys that three companies from different industrial sectors have taken towards transforming their companies. The companies were known to have started on the journey towards sustainability by reducing environmental impacts and were selected because they were sustaining their activities. There was a clear start point in their journey that was marked by a cluster of aspects. This was labelled as the 'Vision creation' step. The companies each had leaders in their companies (which included the interviewees) who were progressing the agenda consistently and (in a polite way) obsessively. The was therefore a distinct cluster of activity around 'Passion in leadership'. All companies described how they went about educating staff within and outside their organisation and it was considered that the education was a step distinct from the communication of advances and successes within and outside their organisation. Two clusters emerged that were named 'Education of people' and 'Broadcast success' respectively. Each company described their approach to improvement, detailed the tools used and placed significant emphasis on the simplicity of their tools to promote adoption. It was challenging to separate the technical approach from the simplicity its use, hence the step of 'Approach with simplicity' emerged. All companies described their first projects as well as the volume of projects. These were two distinct stages. First, the initial activity was within operations as well as against particular technical problems. Second, there was the engagement of many others once success had been proven and confidence gained. The technical activities in both these stages were the same but the mind-set of the first was to be cautious and allow mistakes with small groups of people and the second, still with some caution, was engaging many others in doing the same. Two steps therefore emerged named 'Successful pilots' and 'Develop momentum'. These steps with their corresponding cluster of codes are shown in Table 1.

Table 1 shows the similarities in the approaches taken by each company as well as differences in the methods of engagement, for example automotive at described most activities with reference to a single site, aerospace described activities across multiple sites within the same company and then food and drink described activities with other companies in its supply chain. Table 2 presents a consolidation of the case data to provide generalised aspects against each step. Each case company was different in detail so the aspects for each step represent possibilities for others to use rather than an essential list to enable success.

The steps leading to organisation change within the context of sustainable manufacturing, detailed in Table 2, contain activities that are common to most of the case companies interviewed. Not all aspects for each step are necessary to make progress and for this reason they have not been presented as a sequence or summarised as a narrative to follow. Additionally, it must be emphasised that the steps are presented in the order that they will be typically initiated and it is recognised that many steps will continue in parallel and iterate. For example, training and education will be with a small group of staff working on pilots and will continue as more and more staff are engaged in the overall change programme. Finally, the developing momentum step had a significant cluster of aspects that further research could justify subdivision of this step. For example, some aspects relate to initial expansion whether as others relate to later maturity when sustaining the change is emphasised. Further to this, some aspects relate to internal company activities whilst others relate to the supply chain.

Table 1. Case data clusters as steps for organisational change towards sustainable manufacturing

Steps	Automotive	Aerospace	Food and drink
Vision creation	Sustainability vision, Ambition Journey metaphor Connect to Minimise impact In harmony with nature	Ambitious vision Reduce energy and carbon	Sustainability vision Mantra of practical sustainability Staff aligned to vision Desire to reduce
Passion in leadership	Leaders, champions Belief Win hearts and minds	Support from the seniors Local/Network of champions Nominated by each plant Foster enthusiasm in others Change behaviours	Inspiration Initial motivation Not responsibility of lone leader
Education of people	Share knowledge Overall philosophy Understand the basics Educate on why and how Philosophy of zero	Many staff were trained Inspiration from others Learn from one another Questioning fundamentals Asking/Understanding why	Help others Avoid lack of interest Avoid defensive practices Remove any fear Time & skills to obtain data Wider understanding Discussion & understanding
Approach with simplicity	Go and see Rules for simple process Underpinning principles Fundamental impacts Simplicity of approach Standard process	Standard way of working/process Based on principles Standard process Promoting quick wins Support disruptive projects	Practical mind-set, emphasis on practical/basics and simplicity Desire to demystify Adopting standard methods Fast-tracking analysis Focusing on hotspots Simple effective engagement Not demanding accuracy Matched to data/info available Basics first, clever afterwards Not interested in offsets
Successful pilots	Pilot plants, Proceed cautiously Small/incremental steps Return to known condition Encouraging trying Permitting mistakes Trials were performed	Pilot plant Successful initial projects Generate confidence External funding Understand what works locally External collaboration	Initial progress challenging Initial successes Lack of information
Develop momentum	Long term evolution Persistence Few full time staff Engaging others Sensitive to local conditions Increase activity Central funding Avoid barriers	Network to develop the momentum / to cascade Motivation for change Improvement groups Provide tools/Tailored to needs Help others do projects Avoiding dictating detail Deploy/adopt widely Avoid local inertia ‘Mundane’ changes Success enables expansion Internal/external benchmarking Working with suppliers	Engage others Working with customers Working with suppliers Collaboration with suppliers Initially resisted Perceived as a threat Across the supply chain Benefits were mutual Help others help self Sharing tools and data Advances come from all staff Investing in technology
Broadcast success	Consistent messages Communicate Local relevance Reward and recognition Cascaded awareness/advances	Communicate practices Success recognised Fit with performance system Time to have fun	Interest from others Triple win Staff were surveyed

Table 2. Steps and aspects to support organisational change towards sustainable manufacturing

Steps	Aspects to support
Vision creation	Creation of an ambitious sustainability vision Detail of vision gives staff ability to connect and align Vision provides focus on minimising impact
Passion in leadership	Leaders foster enthusiasm in others to engage Leaders provide the inspiration for changing behaviours Seniors create local champions to ensure the responsibility and activity is shared
Education of people	Staff are educated in an overall philosophy The focus is on understanding the basics and questioning why Knowledge is shared as staff discuss and learn from one another Ways to allay threats and fears are promoted
Approach with simplicity	Standard, simple, practical approach is adopted and developed Approach has core principles that focus on identifying fundamental impacts Approach promotes "go and see" Support for combination of short/incremental projects as well as disruptive projects Analysis is based on available data, recognising some data is hard to obtain
Successful pilots	Early projects demonstrate success (in pilot plants) and builds confidence Progress is challenging in both how to analyse and how to change Work proceeds cautiously with small, incremental steps Staff are encouraged to try and mistakes are permitted in controlled environment Ability to return to known condition important for process stability and confidence Teams learn what works well External funding can help initial work Internal and external collaboration helps initiation
Develop momentum	From successful pilot activity is increased by engaging others over the long term Network/community helps motivate change and increase adoption Activity can be within same plant, other plants, suppliers or customers Few staff with full-time responsibility engage many others through networks/groups In helping others and sharing tools, mutual benefits can be realised Help is provided to overcome resistance/inertia/barriers Persistence develops motivation for change and gain momentum Central funding can help with acceleration of adoption of new methods 'Mundane' process change is promoted and technology change carefully considered Internal and external benchmarking provides awareness of good practice Leaders are sensitive to local conditions and avoid dictating detail / allow tailoring
Broadcast success	Consistent messages are communicated Success recognised within existing performance structure Success is celebrated, often emphasising multiple benefits As advances are cascaded local relevance is ensured Engagement of staff is measured and communicated Communication is local as well as outside plant/company boundary Important to set aside time to have fun

Implications for sustainable manufacturing research

There are similarities in the sequence of steps that would be expected of any project management process (PMBOK, 2013) in which: a project is initiated with a charter (vision); planning with the creation of a team (leadership); executing by setting up a team (education, approach) and then carrying out the work (pilots, momentum); and finally closure (broadcast). Considering the steps as an overall innovation process, the steps share similarities with the more generalised process developed by Rogers (2003). The initial step has characteristics of the understanding potential changes, the potential benefit and what and why they should be pursued. The next steps are about persuading others that the change is necessary and the leaders ensuring compatibility with values and past experience. This is followed by a decision stage of piloting and accepting. Then the implementation of change is adopted more widely, possibly with continued experimentation, before the confirmation stage of communicating, evaluating and gaining support. The reference to the journey rather than an initiative chimes with the thinking on change presented in "Green to Gold" (Esty and Simmons, 2011).

The steps can be related to much deeper fields of study but it is not the intention of this work to create a number of steps and define each step precisely. The purpose of this work is to capture what is important and prominent overall for those engaged in change. Hence the leadership step has aspects that relate to, say, the Sustainability Leadership Model (Visser & Courtice, 2011), of empowering and creating awareness whilst the approach step has aspects that relate to, say, "Green to Gold" (Esty & Simmons, 2011) with the emphasis on the leadership, vision and communication with the differences being around greater emphasis on pilots to instil confidence, education (as distinct from training) and grassroots networks rather than top-down hierarchical control.

The companies used for the data collection were known to have advanced thinking on sustainability and had achieved significant success over the years, e.g. the reduction in energy and other resource consumption. These successes appeared in their annual reports and web pages. Despite the overall company achievements, it is interesting to note performance targets and the quantification of achievements did not feature strongly in the accounts of their sustainability journeys. The outcomes were not part of the prompts for the interviewees to relate the story of their company's journey but they all made repeated references to successes and securing the mandate to continue. However, they focused more on increasing activity rather than giving emphasis to quantified return on any activity as was emphasised by Esty & Simmons (2011). Further research is needed to understand if this emphasis resulted from the maturity of companies' processes for evaluation of return on investment and greater challenge around gaining momentum in such investments or that there is a weak link between sustainable manufacturing leadership and financial performance as suggested by Aspelund & Fredriksen (2016).

Conclusions and future direction

This paper has documented research into capturing the characteristics how companies undertake their journey towards sustainable manufacturing from initiation to supporting wider adoption. Whilst there has been significant research in what achievements have been made, what technical changes have been implemented and what objectives companies are establishing, there has been little on the organisational change companies have taken to reduce impact across the breadth of the organisation. The research here has used a grounded method to interpret the accounts of three companies recognised to be leaders in the field of sustainability and establish common characteristics. Individual cases were coded and the codes clustered across the cases to establish major steps that companies take and common aspects to support those steps.

The research has established a number of common steps that companies have displayed in establishing and accelerating the journey towards impact reduction. Seven steps were uncovered. The first two steps detail how companies created a vision to provide direction to their journey and used passionate leaders to initiate and evolve the journey. The next two steps are where companies educate people within and outside the company on key principles and then deploy simple standard processes for them to use to reduce impact. The fifth step is where pilot projects adapt and develop methods into a company standard and build confidence through early success. The sixth step describes how companies build on the early achievements and accelerate the path along the journey by engaging more people across their company and beyond. The final step sees the companies broadcasting their success by communicating internally and externally. It is acknowledged these seven steps are not linear but operate in parallel as, for example, the communication of success is initially internally and only when momentum builds will companies reveal activity and achievement externally.

The obvious limitation in the work is the examination of only three companies, with each company from different sector, all were in Europe, each differing in size and all at the stage of sustaining a level of activity. Further work is necessary to increase the number of cases to establish saturation in the overall findings as well as uncover any differences between companies of different size, different supply chain power and different maturity in their journey. Additionally, whilst aspects relevant to each step have been identified, it would be valuable to know which factors foster greater advance. For example, how the level of training and education of people or how the level of integration within the existing performance management system impacts on the effectiveness of sustainability focus improvement activities. There was reference to experimentation (as distinct from initial pilots) in which staff were encouraged to try different ways with the expectation that failure is a possibility and should this be the case the change can be undone to the last stable set up. This is a feature noted in mature lean companies but this was not actively pursued in the interviews. There is potential for further research in this area to uncover whether companies are actively promoting experimentation and under what conditions. Finally, the focus here has been on how the companies have focused reducing impact rather than a more positive position of increasing health of the environmental and social system.

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CEO's Motivation and Leadership Style:
Effects on Sustainability Practices in Manufacturing Firms

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Abstract

Stakeholders are increasing pressure on manufacturers to adopt more sustainable practices (Gonzalez-Perez, 2013). Customers are demanding more sustainable products, manufactured in environmental friendly ways and under dignified human work conditions over the whole value chain. Furthermore, 195 governments recently signed the Paris Agreement that will, from 2020, force far more stringent environmental demands on manufacturers. Under these conditions it is timely to launch an investigation of the underpinnings of the process of adoption of sustainability practices in manufacturing firms and the financial implications such adoption might entail.

This study aims to contribute in that direction by asking: *How do business leaders influence manufacturers' strategic sustainability efforts, and does this lead to higher financial performance?* Building on transformational leadership theory (Bass, 1985, 1991; Bass & Steidlmeier, 1999; Burns, 1978), self-determination theory (Ryan & Deci, 2000) and the microfoundational approach of organizational behavior (Barney & Felin, 2013; Felin, Foss, Heimeriks, & Madsen, 2012; Foss, 2011) we investigate the relationship between the CEO motivation and leadership style in international exposed firms and their firms' propensity to engage in sustainability efforts at the strategic level.

More specifically, we investigate the effects of *identified motivation,* which is expressed when an individual act due to consciously valuing and placing personal importance on an activity and its goals (Ryan & Deci, 2000), and the charismatic leadership style of *intellectual stimulation* (Bass, 1985, 1991; Waldman, Siegel, & Javidan, 2006). The latter comprising of business leaders who intellectually stimulates and challenges their employees, making the employees look at problems from different angles and who themselves reevaluate the critical assumptions underlying current business strategies. Finally, we look at the degree to which these antecedents at the micro level increase the firm's likelihood to develop strategic sustainability efforts at the macro level, and its link to financial performance.

The hypotheses are tested in a structural equations model on a sample of 450 Norwegian manufacturers. The sample is a representative sample of the population of Norwegian manufacturers collected through an online survey questionnaire in 2016.

Findings suggests a significant, direct effect from *identified motivation* on the firms' involvement in sustainability efforts. The effect remains significant when adding *intellectual stimulation* as an intermediating factor, meaning leadership style partially mediates the relationship between motivation and sustainability strategy. We also find a significant effect of sustainability strategies on firms' financial performance. The findings highlight the importance of CEO motivation and leadership style on the adoption of sustainability strategies and financial performance in manufacturing firms.

Theoretical background

The literature on sustainable manufacturing is full of leadership dilemmas. For example, there is a long standing discussion concerning if business managers should even consider sustainability practices – illustrated by a famous statement by Friedman saying that "*business for business is business*", and further that the mere existence of sustainability efforts particularly through Corporate Social Responsibility (CSR) signals an agency problem within the firm (Friedman, 1970). On the other side, there are those who argue that corporations have an obligation to be as environmentally friendly as possible and also give back to the society around them (Waldman & Siegel, 2008).

Furthermore, accepting that stakeholder expect more than just taxable revenues from firm activities, how should managers in manufacturing firms deal with those expectations? Should they just deal with them as a cost factor, like many managers in multinationals do (Christman & Taylor, 2006)? Or should they embrace stakeholder expectations of sustainable practices like any other business opportunity as suggested by Porter and Kramer (2006; 2011) and other advocates of Shared Value Creation?

Finally, who are those managers that seek to implement sustainability strategies in their firms? Are they like any other manager, or are they driven by their personal ambitions to do good? And if they are driven by their personal ambitions, do they fulfil these ambitions at the cost of the firm's revenues and profits?

In the literature the relationship between sustainability and firm performance is inconclusive (Goyal, Rahman, & Kazmi, 2013), however recent research suggests a positive relationship (Aspelund & Fredriksen, 2016; Aspelund & Srai, 2016; Eccles, Ioannou, & Serafeim, 2014). Especially, when sustainability efforts are integrated into the corporations' business strategies this leads to better performance and value for stakeholders (McWilliams & Siegel, 2000, 2001; Siegel & Vitaliano, 2007). By constructing such a sustainability-strategy for their international ventures, business leaders have to think differently, be creative, maybe often "start from scratch", thus creating uncharted competitive waters of blue oceans for their firms (Aspelund, Rødland, & Fjell, 2015). Thus, this leads us to the research question at hand: *How do business leaders influence firms' strategic sustainability efforts, and does this lead to higher financial performance?*

Building on transformational leadership theory (Bass, 1985, 1991; Bass & Steidlmeier, 1999; Burns, 1978), self-determination theory (Ryan & Deci, 2000) and the microfoundational approach of organizational behavior (Barney & Felin, 2013; Felin et al., 2012; Foss, 2011) we investigate the relationship between the CEO motivation and leadership style in international exposed firms and their firms' propensity to engage in sustainability efforts at the strategic level.

Hence, in order to address the research question, we consider the personal attributes of CEOs. Organizations are composed of individuals, and therefore a focus on individuals helps to illuminate answers to questions about strategy and performance of firms (Felin & Foss, 2005). Of the individuals in a firm, it is the top managers that affect firm strategy (Hambrick &

Mason, 1984), so it is useful to consider the effects of CEO motivation for sustainability and leadership style on sustainability strategy.

Identified motivation is expressed when an individual acts due to consciously valuing and placing personal importance on an activity and its goals (Ryan & Deci, 2000). As part of self-determination theory (SDT), identified motivation is a relatively autonomous form of extrinsic motivation that has been found to positively associate with various outcomes such as student performance (Burton, Lydon, D'Alessandro, & Koestner, 2006) and information seeking (Koestner, Losier, Vallerand, & Carducci, 1996). More importantly, autonomous forms of motivation (e.g. identified motivation) are related to organizational citizenship behavior, and effective performance on cognitive flexibility tasks and conceptual understanding (Gagné & Deci, 2005), and support has been found for a positive inter-level relationship between managers' transformational leadership and employee identified motivation (Gagné et al., 2015).

Intellectual stimulation is a type of transformational leadership that supports outstanding effort and performance (Bass, 1985). Leaders that express intellectual stimulation influence followers (e.g. employees) by helping and encouraging them to question assumptions, look at problems in new ways, and generate creative solutions (Bass & Steidlmeier, 1999). Intellectual stimulation has been found to be a significant predictor of strategically-oriented CSR (Waldman, Siegel, et al., 2006).

Hypotheses

Upper managers affect firm strategy (Hambrick & Mason, 1984), and if a CEO personally values sustainability then it will likely be implemented in the company strategy. Identified motivation is associated with organizational citizenship behavior and conceptual understanding (Gagné & Deci, 2005), qualities that should be beneficial for the formulation and implementation of sustainability strategy. In this manner, CEOs' identified motivation for sustainability should have a direct and positive effect on sustainability strategy.

H1: CEO identified motivation will be positively associated with sustainability strategy.

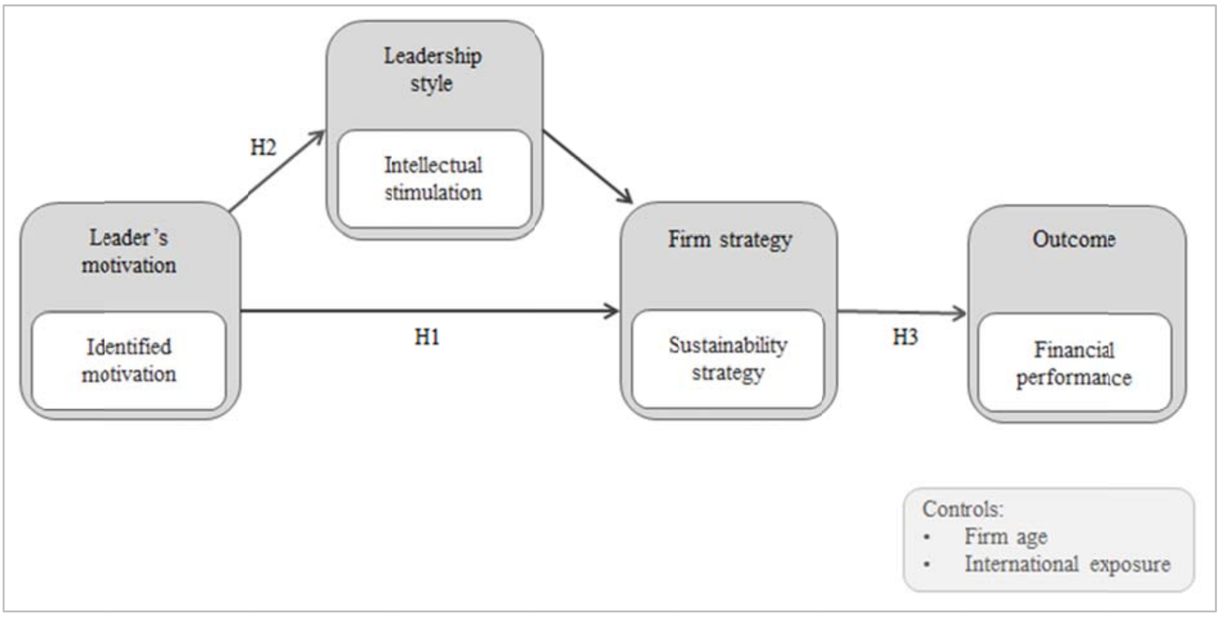
Superior leaders give messages to employees via intellectual stimulation (Bass, 1991). CEO motivation will be influenced by leadership style – a manager's motivation may not be visible to employees, but leadership style is – so intellectual stimulation will act as a conduit for a managers' identified motivation for sustainability strategy. Previous research has shown a positive association between transformational leadership and identified motivation (Gagné et al., 2015). It is possible that this relationship also exists intra-personally since identified motivation can lead to effective performance on cognitive flexibility tasks and conceptual understanding (Gagné & Deci, 2005) – elements that characterize intellectual stimulation. Since previous research provides support for a positive association between identified motivation and transformational leadership (Gagné et al., 2015), and between intellectual stimulation and sustainability strategy (Waldman, Sully de Luque, et al., 2006), and because motivation should be expressed via leadership style and behavior, we propose that intellectual stimulation will mediate the relationship between CEO identified motivation and sustainability strategy.

H2: CEO intellectual stimulation mediates the relationship between CEO identified motivation and firm sustainability strategy.

Ultimately, firm strategy should in some way influence firm performance. Recent research has provided support for a positive association between sustainability and firm performance (Aspelund & Fredriksen, 2016; Aspelund & Srai, 2016; Eccles et al., 2014), and there is evidence of superior performance by firms that integrate sustainability efforts into their strategies (McWilliams & Siegel, 2000; Siegel & Vitaliano, 2007).

H3: There is a positive relationship between firm sustainability strategy and firm financial performance.

The proposed relationships are summarized in the model below:



Model 1: Research framework

Methods

The literature on the sustainability – firm performance relationship is to a great extent dominated by case based research with convenience sampling (Aspelund, Fjell, & Rødland, 2015; Goyal et al., 2013), which renders generalizability of results difficult. Therefore, we have adopted a qualitative approach for this study, targeting the whole population of Norwegian manufacturers.

The population of Norwegian manufacturers were identified through the Brønnøysund Business Register that holds all public accounts of Norwegian businesses. Each firm (~ 2700 firms) were sent a questionnaire with 110 questions related to their sustainability strategies and leadership. We received 682 responses (25.2 % response rate) and a comparison with the total population showed that the sample was representative for the population. Subsequently, we completed the dataset with 10 years of financial data from the business service proff.no.

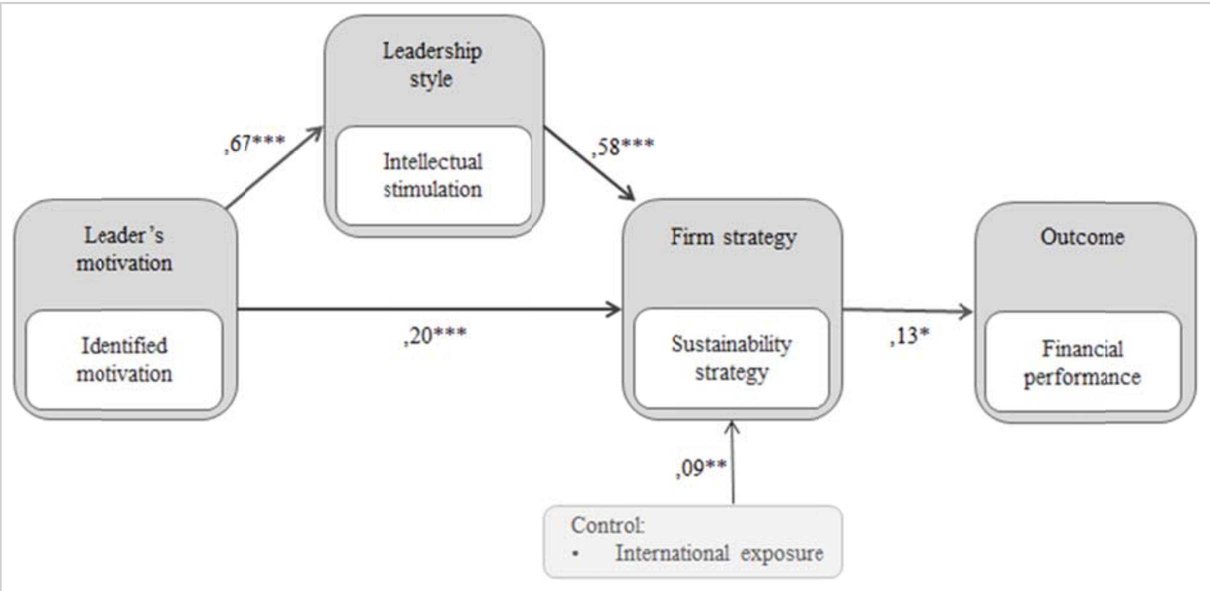
The sample predominantly consists of SMEs, which is in line with the Norwegian industry profile. The responding firms had on average 80 employees and an annual turnover of approximately 33 million Euros.

We investigate the hypothesis through a structural equations model according to the research model above. The total sample was reduced due to list-wise exclusion of missing data. If a respondent had missed more than 10 answers in the survey their entire record was deleted. To be able to perform the structural equations model further missing values were imputed by expectation maximization estimation (EM). The final model ran with 452 firms. All measures used are validated in previous research and reported in table A1 in the appendix.

Results

The analyses reported in this paper were done using SPSS Amos. First an item analysis consisting of internal consistency tests was performed, Cronbach's alpha for all measures was well above 0,7 with evenly distributed loadings. The proposed structure of the items was then confirmed through a confirmatory factor analysis, and the estimated parameters of the measurement model for identified motivation, intellectual stimulation and sustainability strategy may be found in table 1. We allowed no measurement error covariations within or across items.

Model 2: Results Structural Equation Model



Then the model without mediation was run through Amos. Financial performance (FP) was regressed on sustainability strategy (SS) and identified motivation (IM). Table 1 shows the results of the model tests and table 2 gives the model fit indicies for all models. The results show that there is a significant and positive direct effect of the leader's identified motivation for sustainability on the firm's involvement in sustainability efforts. Meaning that the more a leader is consciously valuing and placing personal importance on sustainability activities and its goals (identified motivation) the more we see of sustainability strategies at firm level. The results also indicate that there is a positive and significant relationship between having a sustainability strategy and financial performance. Model fit for this model (given in table 2) was good and neither control variables of firm age or firm international exposure were significant.

In the next step we introduced the intermediating variable intellectual stimulation. Financial performance (FP) was regressed on sustainability strategy (SS) and identified motivation (IM), with intellectual stimulation (IS) as an intermediating variable between IM and SS. The findings show a significant, direct effect from sustainability strategy on financial performance suggesting that the presence of such a strategy is associated with better financial performance of the firm. Furthermore, the positive direct effect from identified motivation on sustainability strategy remained significant, but reduced in size after adding the mediator, suggesting that style of leadership partly mediates the relationship between motivation and firms' sustainability strategy. Meaning that the firm strategic position concerning sustainability will be dependent on the leader's personal values, but the indirect effect of leadership style, the way a leader leads and communicates when it comes to sustainability contributes positively to the firm's engagement in sustainability activities.

For the latter model, the control variable of international exposure was positive and significant indicating that internationally exposed firms are more inclined to incorporate sustainability efforts into their firm strategy, perhaps because they are more exposed to the downsides of poor sustainability efforts. All proposed models show a good model fit (given in table 2).

Table 1: SEM Statistics

TABLE 1	**B**	**S.E.**	**ρ**	**r^2**
Measurement model				
IM → IM1	,901			
IM →IM2	,976	0,26	***	
IM →IM3	,946	,028	***	
IS →IS1	,838			
IS →IS2	,873	,045	***	
IS →IS3	,865	,046	***	
IS →IS4	,864	,044	***	
SS →SS1	,801			
SS → SS2	,922	,052	***	
SS → SS3	,889	,051	***	
Path model wo/mediation				
IM → SS	,586	,554	***	
SS →FP	,130	1,847	**	

Age →SS	,075	,001	ns	
Age→FP	-,016	,022	ns	
Int Exp →SS	,069	,133	ns	
Int Exp →FP	-,009	5,715	ns	
FP				,02
Overall model				
IM →SS	,203	,048	***	
IM →IS	,665	,042	***	
IS → SS	,576	,059	***	
SS →FP	,129	1,844	*	
Age →SS	,057	,000	ns	
Age→FP	-,016	,022	ns	
Int Exp →SS	,088	,116	*	
Int Exp →FP	-,009	-,189	ns	
FP				,02

Table 2: SEM model fit

TABLE 2	χ^2	df	ρ	RMSEA	CFI	TLI
Overall model	102,180	57	,000	,042	,990	,986
Measurement model	83,606	32	,000	,060	,988	,983
Path model wo/mediation	26,888	21	,175	,025	,998	,996

Discussion

Our findings, from a representative sample of the population of Norwegian manufacturers, tells a story of how personal motivation, directly and mediated by their leadership style based on intellectual stimulation, are strong antecedents of the firm's tendency to create sustainability strategies that the firm profits from.

The study provides a novel perspective of the impact of leader motivation on firm strategy and how sustainability strategy can aid firm performance. It contributes to the sustainability literature by showing that CEO motivation acts as an antecedent to leadership style and sustainability strategy, and it builds on micro-foundations and SDT by pointing to the importance of leader motivation, with respect to firm strategy and performance. Although intellectual stimulation has previously been found to affect sustainability strategy (Waldman, Sully de Luque, et al., 2006), it has not, to the best of our knowledge, been considered as a mediator between leader motivation and sustainability strategy. Actually, our findings suggests that the mediating effect of intellectual stimulation is stronger than the direct effect of identified motivation. This finding echoes well with previous studies that suggests sustainability strategies requires a break with existing industry logic, hence the new strategic path is to a great extent unknown, and requires new ideas and innovation (Aspelund, Rødland, et al., 2015). A leadership style, like intellectual stimulation, seems beneficial in such situations as it draws on the creative resources of the whole organization.

Since this study provides evidence that identified motivation is associated on an intra-personal basis with intellectual stimulation and sustainability strategy mediates this relationship, it implies that CEO motivation and leadership style are factors that are intertwined and should be considered when analyzing firm strategy.

Managerial implications

Our study provides an example of the effects of CEOs' personal attributes on sustainability strategy and the consequent impact of sustainability strategy on firm performance. The results of this study indicate that it behooves CEOs to formulate and implement sustainability strategy since it positively impact firm performance. However, before this step, CEOs must internalize and identify with the value of sustainability and make concerted efforts to inspire their employees to challenge assumptions and think openly and differently about sustainability.

Limitations and further research

Even though the current study has been performed on a representative sample of Norwegian manufacturers, it remains to be seen whether the results transfers to other country settings. Some might argue, and probably rightfully so, that due to characteristics of the Norwegian industry and the strength of Norwegian institutional stakeholders, the result might transfer poorly to other country settings – especially low cost economies. Further research is needed in order to establish whether the relationship between sustainability strategies and firm performance travels well to other economies. However, when it comes to the findings related to H1 and H2, these are based on general human and organizational behavior and there is little to suggest that these features are any different in Norway than anywhere else. Our analyses are based on a limited dimension of transformational leadership (*intellectual stimulation*), and only one form of motivation (*identified motivation*). Further research needs to establish the role of other dimensions of transformational leadership and motivation forms.

Conclusions

Our findings show a significant, direct effect from *identified motivation* to the firms' strategic involvement in sustainability efforts. This effect remains significant, and even strengthened, when adding *intellectual stimulation* as an intermediating factor. This finding suggest that leadership style partially mediates and amplifies the relationship between motivation and sustainability strategy. We also find a significant effect of sustainability strategy on firms' financial performance. The control measure firm age shows no significant effect, meaning that there is no difference between the proposedly resource scarce young firms and older firms that may have more resource slack when it comes to strategy implementation. However, when we control for internationalization we find that international firms are significantly more likely to have a sustainability strategy than domestic firms. Our findings highlight the importance of CEO motivation and leadership style on sustainability strategy and financial performance in firms.

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Appendix A

Table A1 - Measures

***Scale*/Question**	**Measure**
Identified regulation	
Because I personally consider it important to put effort into this work	1-7 Likert scale
Because putting effort into this work is consistent with my values	1-7 Likert scale
Because putting effort into this work has personal significance to me	1-7 Likert scale
Intellectual stimulation	
We regularly reconsider the assumptions our sustainability strategy is based upon	1-7 Likert scale
We seek to use different perspectives when we make decisions related to sustainability (environment and society)	1-7 Likert scale
We encourage employees to look at environmental and social challenges in new ways	1-7 Likert scale
We often suggest new ways of solving environmental and societal challenges	1-7 Likert scale
Sustainability strategy	
Sustainability (environment and society) is an inspiration to ongoing improvements in our production - we reduce costs through sustainability	1-7 Likert scale
Sustainability (environment and society) is integrated into our business strategy - we see new business opportunities in sustainability	1-7 Likert scale
Sustainability (environment and society) is a fundamental value for our business - we want to change the industry we work in	1-7 Likert scale
Financial Performance	
Operational income growth	Monetary

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Can Life Cycle Product Communication Contribute to Greener Business Development?

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Abstract

Many manufacturing companies have limited insight into the complete life cycle of their products. One possible solution to this challenge is to apply emerging sensor technology or smart technology for communicating with products.

Accompanying digitalization of industry, an increased focus on how sensors can be utilized for developing better products, zero defect processes and more effective value chains is seen. However, little attention is given to how product communication may improve environmental sustainability for the product's life cycles. Based on a planned case study, a list of proposed areas where product data may be utilized for greener business development is presented. The areas discussed are sustainability planning and reporting, design and innovation, process and improvement work and end of life planning.

Keywords: Environmental sustainability, circular economy, industry 4.0, end user insight, life cycle data

1. Introduction

The coming decade is expected to become a crucial period for industrial companies as they more frequently have to respond to global challenges. Environmental awareness is growing throughout the society and the pressure on manufacturing companies to operate in an environmental sustainable way is increasing. Having control of, and insight into, the entire value chain is becoming a significant part of running a business. However, for many manufacturing companies that are not distributing their products themselves, knowledge of the complete life cycle of the products is limited. Furthermore, insights into users and end of life stages are particularly restricted. Understanding these stages are important for facilitating a long-term sustainable business development. On the other side, the amount of available technologies for enabling information tracking throughout the product life cycle is increasing. The manufacturing industry is experiencing a shift towards more machine and technology driven manufacturing, of some referred to as a 4th industrial revolution. The discussion on how new technology can be used to develop better products, zero defect processes, transparent and effective value chains etc. are central elements in the industry 4.0 initiative. However, little attention is given to how all these new possibilities may improve environmental sustainability impacts for the entire product life cycle or for securing material loops. Based on the challenge with lack of information and knowledge from the product life cycle a case study is planned. The study assumes that manufacturers can gain valuable information from the use-phase as well as end of life of their products by utilizing an integrated sensor technology that can communicate throughout the product's lifetime. The integrated sensor may consist of different technologies that can harvest data from the products and its' environment before they leave the factory gate, throughout the use and lastly to final disposal.

This paper presents theoretical considerations and background for a research driven innovation case that starts 2016/2017. The descriptive case study elaborates enabling sensor technologies for improved product environmental performance. The paper discusses how a manufacturing company can use and benefit from this type of data gathering. The research case attempts a practical and technology driven approach towards greener business development.

The cooperating company is a producer of LPG (liquefied petroleum gas) containers. In the case study we plan to add sensors to the containers that will communicate between container and producer and maybe also other users in the value chain. LPG containers are global products. The lifetime of the LPG containers is highly uncertain and very dependent on where in the world the LPG container is used. Depending on the geographical market, LPG containers are used for various purposes; for cooking at home and in restaurants, at building sites, for heating or for barbeque. The knowledge on the whereabouts of the containers after leaving the factory gate is very limited. By adding sensors, we believe valuable information may be gathered.

Since this is a research case study that is currently under development, the scope of this paper is limited to addressing opportunities for utilizing this type of sensor tracking to improve the environmental performance of products and provide a basis for greener business development. Real empirical data from the tracking will not be assessable during this pre-project stage, but will be released in further research. This case study is a pilot project, therefore only one product type is considered.

The goal of the planned case study is to explore the possibilities for sensor tracking of products through its life cycle. The results from this case study will provide information on what types of data that is assessable from this type of tracking and how this data may facilitate a greener product life cycle and greener business development for manufacturing companies.

This paper first discusses relevant literature and studies, before presenting the case company. Thereafter four areas of application for product life cycle data for developing greener businesses are proposed. Finally, we introduce some challenges with applying sensor technology through a product's life cycle.

2. Theory and literature review

2.1. Product monitoring, tracking and communication

Industry 4.0 is a global trend also referred to as the 4th industrial revolution based on Cyber-Physical Systems (CPS), Internet of Things (IoT), or the Industrial Internet. An important feature of the 4th industrial revolution is application of CPS for merging the physical and virtual world. CPS are systems of computers and networks used for monitoring and controlling physical processes, usually with feedback loops (Lee, 2008). CPS have developed through three stages (Hermann *et al.,* 2015). The first generation CPS includes identification technologies like RFID (Radio Frequency Identification). The second generation of CPS have sensors and actuators with limited amounts of functions, whereas the third generation involves CPS that are network compatible and can store and analyse data.

Sensors is widely used for many purposes, in logistics and transportation for control, object identification and all kinds of diverse applications areas. A sensor detects a value or a change in a value, like pressure, temperature, vibration and converts it into a signal (Ondemir and Guptra, 2008). There is a wide range of functionality of sensors, and they come in a wide range of sizes and with or without an external power source.

2.2. Sensor technology for improving environmental performance

The attachment of a sensor to a product is not in itself a green technology, due to adding electronics, materials and possible energy sources to power sensors. This leads to larger demands for raw materials and energy usage. However, by its function, a sensor may provide and help facilitate solutions that may improve products environmental performance throughout the life cycle. The amount of literature available on the use of sensors for improvement of environmental sustainability impacts appears to be limited. Most of the studies that are published focus on the use of RFID for improving environmental performance.

CPS and sensors is a way of communicating with products and this communication may provide opportunities for greener value chains and product life cycles. Through development of new solutions, sensors and RFID may give access to information that can be used to achieve more efficient energy use, reduction of CO2 emissions, improved waste control and improved recycling rates (Duroc, 2012).

The potential for environmental improvements is investigated in an analysis of 13 case studies of RFID use (Bose, 2011). The case studies were selected from published studies on RFID use with a strong green objective. By analysing the case studies, the authors found that 10 of the 13 analysed RFID projects have a strong impact on environmental sustainability. The impacts where reduced by different measures for the different case studies, from reducing the amount of trips due to improved inventory management (Karakasa, 2007), to reduced traffic congestion due to faster and automated driver security inspection (O'Connor, 2007).

Integrated sensors may be used for monitoring, detection and prediction of product failures, as well as estimating the remaining life of product components (Vadde *et al.*, 2008, pp. 91-104). This may provide a basis for improving environmental sustainability by changing existing end of life processing. For WEEE (Waste of Electrical and Electronic Equipment) recycling effectivity may be raised by improved product information and product identification from RFID technology (Luttropp and Johansson, 2010). In a study of RFID and the recycling industry (Schindler *et al*., 2012) two ways in which RFID is linked to the recycling industry is examined; through the waste handling of the RFID tags itself and through the possibilities for improving recycling by using RFID tags.

2.3. The 4th industrial revolution and sustainability

By networks of computers, sensors and actors integrated in materials, equipment, packaging and machines, industry 4.0 allows customer adapted and differentiated products and new product-service combinations. It also promotes added functionality, such as shorter time-to-market and supply-based production, and calls for closer interaction throughout the value chain

(Kagermann *et al.*, 2013). By communication across the traditional boundaries, tracking product with sensors and collecting data, products, processes and entire value chains can be optimized in respond to particular demands.

An important feature of industry 4.0 is that analysing large amounts of data, will provide insights on current situations and is believed to provide an updated basis for decision-making. Real-time information and visualization of data can be used for improving manufacturing, innovation or to understand new contexts, possibly faster and easier than before. The initiatives to provide frameworks for tracking of products in an industry 4.0 perspective is largely debated, however less effort has been put into addressing the possibilities and opportunities for using this type of information for improving the sustainability performance. The 4^{th} industrial revolution brings a new approach that can influence both the social and the environmental perspective of sustainability. Of particular interest is the social impacts of the future of work, and as for the green dimensions of sustainability, possibilities for improving resource efficiency, and improving continuous energy management (Gabriel and Pessl, 2016).

Stock (Stock, 2016) provides an overview of the main trends of the 4^{th} industrial revolutions, and list the opportunities it brings for sustainable manufacturing. The possibilities is divided into micro perspective with opportunities for equipment, humans, organizations, process and product, and macro perspective with opportunities for business models, value creation networks, equipment, humans, organisations, process and product. A holistic resource efficiency, facilitating cradle to cradle thinking and sustainable process design is some of the main features highlighted.

3. The case study

The case company is an experienced producer of LPG containers. Over 10 million units of their product is currently in use and represented in markets worldwide. The LPG containers is produced in six standard sizes and with a propane capacity ranging from 5 to 14 kg. The containers are designed to operate across all weather conditions from –40 degrees Celsius to +65 degrees Celsius.

The LPG containers are used for many purposes like recreation (e.g. camping and barbeque), cooking and heating. How and to what purpose the LPG containers is used varies, and depends highly on geographical region. In some parts of the world, the containers are used for everyday cooking and indoor heating whereas in other regions they are mostly used for barbeque and outdoor heaters. The intervals on which the containers needs refilling is therefore highly dependent on where in the world the containers are purchased and used.

The case company is a relatively new business, with sparse knowledge of sustainability work and tools for addressing environmental issues. CSR initiatives has traditionally originated from customer inquiries. The company's first involvement with systematic sustainability work and the environmental assessment tool life cycle assessment (LCA) was when customers started to ask questions about waste management of disposed containers. The LPG containers have a long lifetime (estimated to be >10-15 years), therefore the waste handling of a large volume of containers has a relatively long time delay and is a challenge who has yet to come.

The life cycle of the LPG container is complex because of the different types of markets, users and end of life options available. The LPG container is not sold to end users directly, but rather to a retailer or gas distributor, i.e. the producer operates in a B2B market. However, customer feedback is crucial in order to understand costumer requests on end-of-life treatment for the product, and for maintaining their competitive position by developing and improving their products.

A simplified overview of the products life cycle is presented in figure 1. The life cycle starts with the production of the LPG container at the production facility with raw materials bought from different suppliers. After production, the LPG containers are sold and transported in large quantities to distributers all over the world. The distributer sells containers to a retailer. The end user buys the LPG container from the retailer, with gas, and returns it when it is empty in exchange for a new container. The distributer is responsible for any repair and maintenance of the LPG container. LPG containers reaches end of life when the distributor find that they are not functioning in a satisfying way or after a certain amount of time, according to region specific regulations. In addition, some users are disposing their containers outside the regulated recycling plan, for instance by leaving them at building sites.

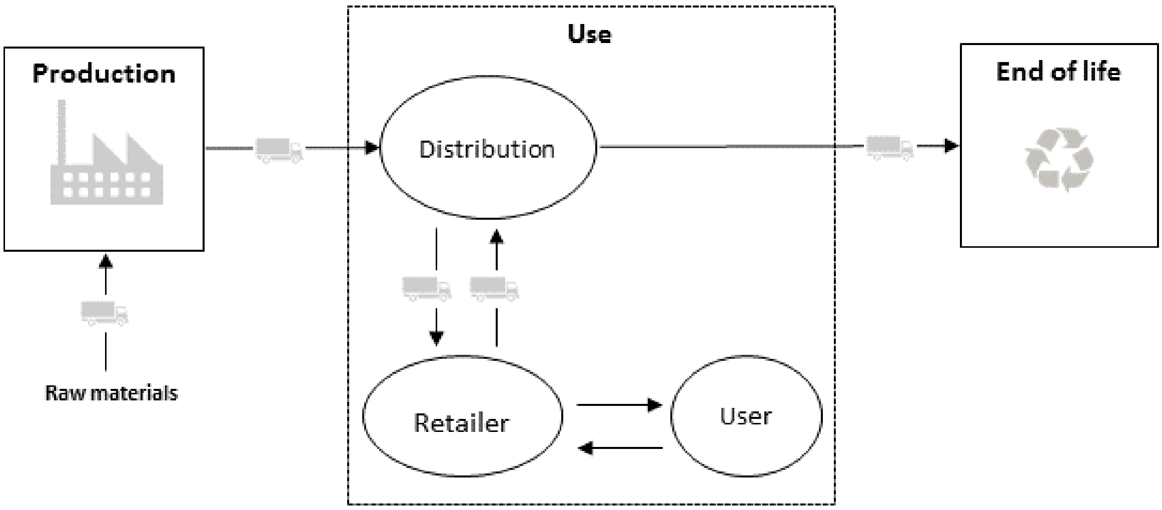

Figure 1: A simplified overview of the life cycle steps of the LPG container

How the LPG containers are being disposed is highly dependent on in which geographical area they are purchased. Since this is a relatively new product, to the knowledge of the company, the largest share of containers are still in use.

Due to this complex use stage for the LPG container and following many options for disposal, the manufacturer lacks a satisfying amount of knowledge on their product. For the case company tracking of their products may give

(1) better knowledge on their end users,
(2) provide information on the containers such as service life, maintenance, replacements, and recycle options,
(3) provide information on the user patterns in different geographical regions, such as transportation distances, refill frequency etc,
(4) information on the quality of the containers, measure and detect damages, and
(5) provide different types of services for end user, such as two-way communication with tips for proper handling, warnings when the product is not functioning well or when it is time for a maintenance check.

4. Proposed areas of application for product data for creating greener business models

There are several motivations for the case company for tracking of products, all not necessary improving environmental sustainability for the product. The focus of this article is how tracking may be used for this purpose. Listed below are four areas of application of data obtained from product sensors, by communication and tracking, which are believed to contribute to enhance the overall environmental sustainability development of the case company.

4.1. Greener sustainability planning and reporting

The global issue of climate change, as well as other environmental issues, has been given increased attention during the last decades. The business world is affected by this awareness, through a substantial increase in the amount of necessary reporting on these issues, demanded by governments through laws and regulations or by stakeholders. The complexity of this kind of reporting has also increased together with the awareness, and the access to qualified personnel for executing this reporting may vary from company to company. Several tools for addressing the environmental issues and facilitate reporting are developed. Life Cycle Assessment (LCA) is one of many tools used for reporting and environmental sustainability planning by companies. However, it is a complex tool and challenges with data availability and data quality often occur (Reap *et al.*, 2008). Improving data availability and quality, by utilizing sensor data, may simplify and lighten the work efforts put into this type of reporting.

LCA is divided into four interacting parts; goal and scope definition, inventory analysis, impact assessment and interpretation. The inventory analysis, the second part, is where data for the relevant inputs and outputs are gathered and quantified for each phase of the life cycle. Lack of data with sufficient quality for use and end of life of products is often a problem in life cycle assessments, and affects the applicability of the obtained results (Baitz *et al.*, 2013, Finnveden *et al.*, 2009). Results may be particularly sensitive to accuracy of some of the data that are used, and this leads to strict demands for high quality data. Improved data will not only make LCA more robust, but also improve its role as a decision making tool. By tracking products and gaining insight into user patterns, service and maintenance patterns and part replacement history, data improvement may be feasible, and provide more robust LCA results.

Besides the authority and governments demands for environmental reporting, the case company has received inquiries from customers to respond to such requests. Increased knowledge on environmental issues for their products is necessary. There may also be strategical benefits in increased environmental knowledge on their product, as more and more consumers is concerned with environmental issues. It will be a competitive advantage if they can promote their product as the greener choice.

4.2. Greener design and product innovation

Ecodesign appeared as a term in the 1990s as an approach to achieve more environmental friendly products. The concepts embrace a broad spectre of design approaches, ranging from tools for improving particular aspects of a product, to system approaches aiming at radically reduce resources and energy necessary to solve tasks in society (e.g. running an office, or providing drinking water to a city). Around 2000 the term Design for sustainability was established to embrace environmental, social and economic aspects of product and service systems. The United Nations Environment Programme argues that design and innovation is a key to creating change in a sustainable direction (UNEP, 2009).

The point of departure for industrial design is the end user, on an aggregated level for example ergonomic or through deep user insights. Insights are achieved through interviews, observations, experiences or through co-designing with the users (Sanders, 2008). Most design methodologies are based on qualitative studies of a very limited group of users.
In design research, the aim of design for sustainable behaviour is to create products in such a manner that they are supporting greener choices and use of products. A simple example is water kettles with choice of 80, 90 and 100 degrees Celsius. Such a design approach requires insights into how users are actual using a particular type of products, for an LPG container this can be information on containers that are not returned to a distributor for proper end of life treatment. Data generated through sensor might amount to insights into different user habits and use-patterns, that are more or less environmental efficient. The analysis can itself constitute a point of departure for product improvements or motivate a more in-depth study of users in a particular market.

Many manufacturing companies that do not have control over the distribution chain are finding it difficult to obtain information on end users. After leaving the factory gate, the products are handled by several other actors before reaching the end user. In some value chains information on the user stage reaches the manufacturer, at least through complaints and mistakes. However, for other value chains information exchange is very limited, due to lack of motivation for sharing knowledge (for example the food retail sector) or lack of understanding of what information that is important for developing greener solutions. Sensor data might provide information on use patterns, which can support design for sustainable behaviour.

Manufacturing companies often receive complaints and information on malfunctioning products. Sensor aggregated data might offer some explanation to why the product failed and thereby support the design process. In design processes applying user observations and interviews, sensor-generated data might correct any biases caused by small number of users studied. Finally, sensors might generate relevant insights and information when direct contact with users are difficult. In general, insights aggregated from sensors is believed to provide useful information, in particular in combination with other data. However, to develop more disruptive sustainable solutions, insights into user practice and behavior are also necessary (Pettersen, 2016).

4.3. Greener process innovation and improvement work

The 4th industrial revolution can be seen as a transformation towards CPS enabled manufacturing and service innovation (Lee *et al*., 2014). More software and embedded intelligence integrated in industrial products enables improved monitoring of systems, which in its nature may contribute to improved environmental performance of the products due to potential energy savings, resource efficiency and waste reduction throughout production. An example of such savings is internally cooled tools, which may reduce energy use (Stock, 2016). Keeping track of machine health may prolong its lifetime, avoid production stops, repairs and replacements. Product control may also provide basis for a backwards reasoning through using product quality to analyze the machine condition (Lee *et al.*, 2014).

Advanced countries with an economic base in the manufacturing industry is experiencing the increasing competition due to globalization and emerging markets. This has led to an increased focus on combining product, services and support for keeping the competitive advantage (Lee *et al.*, 2014). By combining multiple functionalities in one product, the pull on resources may be decreased due to the replacement of multiple products with one product. A shift towards selling functionality and accessibility of products instead of selling only products may significantly lower environmental impacts (Stock, 2016).

As for the case company, introducing a product in an existing market, competing with solutions that has been on the shelf for decades, with new materials and material combinations is a challenge. The company has validated test methods for durability and impact, but the market has defined 10 years as guarantee period for this relatively new product. Thus, the company wants more product information throughout the use phase to both learn more about user patterns in order to improve next generation products, but also to in real time be able to withdraw products from the market if wear, usage, impact etc. overdue certain threshold limits. Such a two-way communication between producer and customer can inhibit unwanted incidents as well as extend the product lifecycle. Another option, seen from the manufacturing view, is to better predict future market demand, knowing with increasingly precision where and when the demands occur.

4.4. Greener waste handling - Closing the loop

A part of moving towards a sustainable society and limiting the temperature increase caused by global warming is reducing the emissions of greenhouse gases. A large share of the emissions is caused by production of goods and services. An escalation in the depletion of virgin resources is seen due to increased customer demands for new products. This is especially true for electronics. This is a threat to the environment for several reasons. Mining and extraction of virgin materials is often associated with several environmental consequences, increased CO_2 emissions, toxicity for humans, ecosystems on land and water and other emissions to air to name some. Besides the problems already mentioned, a decrease in availability for several virgin metals leads to a need for an improvement of take-back systems for products after service life. It is crucial to reduce the draw of primary resources, and keeping materials and resources in the loop, i.e. a shift towards a circular economy. Information on what happens with each product after its main purpose is fulfilled is essential for achieving this.

One way to simplify end of life systems is to make decisions based on acquired product information from monitoring devices (sensors) embedded in the products. Tracking of products may give information on products that can enable correct waste handling, ensure proper handling of products with safety issues (explosive gas), simplify and facilitate sorting and recycling. This may provide basis for a larger degree of take back of materials and easier sorting, which is a huge step towards closing the material loop. Thus, acquiring product data, both product information and data from the product's useful life, has become important for product manufacturers (Ondemir and Guptra, 2008).

What kind of end-of-life treatment a product should be subjected to depends on the original design of product, but also several factors influenced by its use; environmental conditions (hot, cold, dusty, moisture), maintenance frequency, upgrades and other use conditions (Ondemir and Guptra, 2008). Sensor technology may fulfil the mentioned needs for information.

For the case company information provided by attaching sensors may be used for designing a framework for region specific end of life recommendations that may be communicated to their customers (the distributor). Information provided may simplify decisions on whether or not the

LPG containers can be used longer or if they should be disposed. It is possible that fully functioning containers is disposed because of strict regional regulations on LPG containers, due to safety issues. More product information may be used to avoid this and ensure that containers that should not be used is taken out. The information may also be used to make decisions on whether or not the problem may be fixed by repairing or replacing parts rather than disposal of the container. This is beneficial from a resource perspective.

Other valuable information that may be reported back is statistics on how many containers that reach end of life and how many is lost in the use stage. Information from the manufacturer may also be used by end of life actors to decide which disposal option to choose. Today, an increased complexity of products is often seen, with more and new materials and material combinations. Tracking gives the possibility for integrating this type of information in the container, and making it available for the end of life handlers.

5. Results and Discussion

There are several issues associated with the implementation of sensor technology and carrying out the planned case study. Some of the issues detected are discussed below.

Data security

The adding of a sensor that may be used for communication and tracking of a product after factory gate is complicated due to issues regarding data retention, security and customer privacy. It may be argued that the privacy of the user is threatened, and therefore the ethical dimension of product surveillance must be carefully considered before carrying out the case study. Factors affecting consumer acceptance and privacy issues of the usage of RFID technology has been investigated in earlier work (Hossain and Pyrbutok, 2008). They found that, on the contrary to prior literature, the privacy issues is not significant and give two possible explanations for that; (1) Customer does not know that their privacy is threatened due to the nature of the technology implementation, and (2) the customer does not pay much attention to such issues. They also provide a third explanation, which is based on the technology growth we are witnessing today that may lead to a change in people's perceptions about privacy issues. The perception of the degree of privacy problems also varies with personal tolerance (culture) and the purpose of the specific sensor (Ohkubo *et al.,* 2005).

One way of assuring the security for the user is to hide part of the information stored. Users may also be given an option to remove or kill/partial kill sensor function as a step towards assuring the privacy and security of the user (Schindler *et al.,* 2012).

Technological challenges

Choosing the best suited technology is a complex issue, several aspects must be taken into consideration. By using only tags to monitor the containers, one is dependent on the readers to read and store data. Adding sensors that are more complex will be more costly, but also add weight to the product. Depending on what the purpose with the tracking is, and the physical challenges with size and external electricity source, an in-depth analysis of the pros and cons of different technology options should be performed.

Time delay for products with long lifetime

For products with a long life, there is a time delay between the product development and end of life, which might limit how the company can utilize the data. As for the case study, the lifetime of the LPG containers is highly uncertain. It is however, assumed that the container may be used for 10 to 15 years. This may lead to a delay on available information on end of life treatment and maintenance. It is likely that the design and development process has changed significantly during the last decade, and thereby impairing the value of the data for these processes as well. Although the value of some of the data diminishes with time, this is not true for all the application areas. Real-time communication with the product may add value to the consumer and give useful information to the manufacturer.

The environmental footprint of the sensor
The attachment of sensor technology to a product leads to increased material, energy and resource use associated with the product. The increased use of raw materials for producing the sensor, and a possible energy need for operating it, will contribute further to a negative impact on the environment, and increase the overall environmental footprint of the product. The addition of a sensor will also possible further complicate the final disposal of the product, by introducing more materials, complex structures and possibly detachment issues. For this reason, the addition of a sensor to improve environmental performance should be weighed against the material challenges the recycling of the product (and sensor) introduces (Schindler *et al*., 2012).

6. Conclusion

The implementation of sensor technology on existing products provides opportunities for better control of products throughout the use stage of the life cycle and into the end of life stage. It may be argued that this is in itself a way of making the products footprint greener, since information and knowledge on the whereabouts is a foundation for making environmentally preferable decisions. However the addition of electronics, materials and possible an external electricity source in sensors lead to a larger pull on resources. The need for a sensor and the possibilities for utilizing the gathered information should be carefully weighted towards the increased resource use associated with the sensor.

However, the opportunities associated with sensor technology for improving environmental performance are numerous. Through increased knowledge that can be utilized in the product development and innovation phase, in process development, sustainability planning and reporting, and for end of life decisions, sensors have a large potential for minimizing environmental footprints of products.

For the planned case study, it is likely that product communication may add value for customers (both distributors, retailers and end-users) and for the manufacturer. The gained insight to the products after factory life, will strengthen the decision basis for product development and end of life treatment, and provide foundation for, and strengthen the data for environmental analysis. Documenting their products environmental impacts, in a business that is not largely concerned with CSR issues, may be a competitive advantage.

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Someone Rises Someone Falls: Exercise of Dynamic Capability vs ad hoc Problem Solving when Facing Similar Challenge from Intellectual Properties

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Keywords: intellectual property, dynamic capability, emerging multinational

Abstract

Intellectual property is of vital importance to high-tech manufacturing enterprises, latecomers in industry could easily be attacked by their international competitors in IP because of their weak positions, and sometimes these strikes are fatal. Two rising emerging multinational manufacturing enterprises encountered similar challenges from IP in the process of internationalization, with their different ways addressing the problem, they've took distinct path of development. The lawsuit with Cisco served as a watershed for Huawei's development of IP, from then on, Huawei developed its IP systematically and rapidly. Through more than 10 years' hard work, Huawei have become one of the IP giants of telecom industry. However, the lawsuit with Apple made HTC stuck in the mire of IP, and now HTC has nearly reached the verge of bankruptcy.After careful investigation, we view that, when facing challenge from IP, Huawei's countermeasures and long-term developing strategy were exercises of dynamic capability, its successful development of IP was based on its ability to align environmental change with internal reconfiguration; what HTC has done was just ad hoc problem solving. Through comparative case study, this paper endeavor to emphasize the importance of dynamic capability for a company to earn sustainable competitive advantage and refine the theory of dynamic capability perspective.

FINANCIAL MANAGEMENT TRANSFORMATION IN HUAWEI

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Abstract:

Management transformation in the financial management area has contributed significantly to the competitiveness of Huawei. Four Standardizations was the first large-scale financial management transformation project implemented in the company from 1998 to 2007. In 2007, Huawei started a more ambitious Integrated Financial Services project with assistance from IBM consultants, which lasted until 2014. This chapter documents the background, motivation, activities and impacts of these two financial management transformation projects and discusses Huawei's experience in successfully implementing management transformation in the financial area. It also highlights that Huawei's employee ownership and financial management strategy with its own characteristics determine the focus of the financial management transformation projects.

Key Words: Emerging multinationals (EMNC); Huawei; Financial management transformation; Integrated financial services; Employee stock ownership plan

1. Introduction

Huawei was established in 1987 in Shenzhen as a sales agent for Hong Kong companies that produced Private Branch Exchange (PBX) switches. In 1991, Huawei entered the telecommunication industry with its own Research and Development (R&D) capability. Since then, Huawei has committed to continuously innovating based on the core value of staying customer-centric and inspiring dedication. After nearly 30 years of rapid development, Huawei has become a global leading Information and Communications Technology (ICT) solution provider (Huawei, 2016a). In 2015, Huawei's revenue reached USD 60,839 million with its products and services used in more than 170 countries (Huawei, 2016b). During this process, Huawei continuously engaged in management transformation. The company launched a number of large-scale transformations, such as Integrated Product Development (IPD), Integrative Supply Chain (ISC), and Integrated Financial Services (IFS) to improve its management efficiency. The Integrated Supply Chain management transformation represents the efforts in improving management of tangible assets, while the financial management transformation indicates the endeavors in improving management of intangible assets (Mudambi and Puck, 2016). Because IFS was a relatively recent transformation that merely concluded in 2014, existent studies on Huawei have yet document these changes.

Our study is centered on two major financial management transformation projects that were implemented in the Huawei history, that is, the Four Standardizations project (1998-2007) and the IFS project (2007-2014). What has been transformed in these two projects are not primarily the ways that Huawei conducts investment and financing decisions, which are typically two main functions of the financial department of a company (Brealey et al., 2011), but the financial accounting practices of the company. The reason for this focus lies in the ownership of the company and the leadership's management philosophy.

Huawei is a private company wholly owned by its employees. The Union of Huawei

Investment & Holding Co., Ltd and the founder and CEO Ren Zhengfei own the company. As of December 31st, 2015, through the Union, 79, 563 employees participated the Employee Shareholding Scheme. Ren Zhengfei is the individual shareholder of the company and also participant of the Scheme. However, in total he only held nearly 1.4% of the company's total share capital (Huawei, 2016b). Equity financing, that is issuing stocks to the employees, has been a major channel of raising capital since the company's foundation and debt financing was only supplementary (Peng, 2016). Therefore, financing decision making process was not overhauled in the company's history. Since the early stage of the company, Ren Zhengfei has held a view that Huawei's financial management should not only support business growth and expansion, but also control for risk and supervise business activities. He opposed using project returns as an indicator to make investment decision but highlighted the supporting role of financial management system in the company (Huawei, 2016c; Peng, 2016). As Huawei applied this principal consistently along the years, the investment decision making process has yet been the focus of the two major financial management transformations. Nevertheless, Huawei's financing and investment activities greatly contributed to the success of the company, which we will discuss in more detail in Section 7.

The first large-scale financial management transformation project, Four Standardizations, was carried out in the period 1998-2007 with the goal of standardizing financial processes, policies, accounting subjects and control systems. A more ambitious IFS project was launched in 2007 and concluded only in 2014 to connect the business process and financial process. The IFS project was considered by the Huawei top management team as a measure to upgrade the financial management capability of company, address the internal operation risk and management inefficiency and mitigate the external competition pressure. The project as a whole was divided into two stages, IDS I and II, which were designed to connect the financial and business departments to make the accounts accurate and establish responsibility centers and build up project financial management capability, respectively. Similar to other management transformation projects, Huawei focused on forming new processes, reforming organizations and developing new IT tools in the IFS project, which can be considered the output of the project. The process, organization and IT tools reinforced one another and contributed to the success of the IFS project.

The classical financial management and international business theory argue that because Multinational Enterprises (MNEs) operate in the countries with different market and regulatory environments, the key requirement for their success is the ability to maximize the returns from arbitrage in terms of the movement of goods and services. Financial management which regulates capital movement thus has to mesh with supply chain management which administers movement of tangible goods and services to maximize performance (Dunning,1977; Mudambi, 1998). The financial management problems that Huawei encountered in the course of growth and internalization and the solutions that it adopted to mitigate the problems can be explained by the classical theories.

However, Huawei's financial management clearly possess its unique feature. For example, financial management completely serves the overall business strategy. Investment decision is not made by comparing the returns of various projects, but based on the strategic importance of the projects to the core business of the companies. This principal has not changed since the foundation of the company. Financial department plays a supportive role in business development, but importantly also serves as monitor and controller of business development. The project and division leaders need to acquaint themselves with financial management knowledge and the financial managers have to understand business. We will analyze how these principles and rules affect the financial management transformation in Huawei in the next sections.

We collected materials from a number of public sources such as academic journals, news reports, official websites and Huawei annual reports for this study. We also interviewed several former Huawei senior executives regarding the financial management transformation. We organized the rest of the chapter as follows. In Section 2, we introduce the first financial management transformation in Huawei, Four Standardizations. Section 3 presents the IFS background. Section 4 introduces the two stages of IFS and highlights several key sub-projects at each stage. Section 5 discusses how Huawei promoted IFS, Section 6 documents the contribution of IFS to the overall performance of the company and Section 7 discusses the financing, investment and acquisition activities which are important parts of financial management of Huawei. Section 8 concludes.

2. The First Financial Management Transformation Project-Four Standardizations

After several years of high-speed growth since its foundation, the low level of management at Huawei appeared to be a bottleneck for the continued growth of the company in the mid-1990s. In 1995, CEO Ren Zhengfei invited five professors from Renmin University of China as consultants to improve its management. The joint efforts of the professors' three-year long consulting work and the involvement of the Huawei leadership resulted in a management principle document titled with "Huawei Basic Law", which contains six chapters, 103 articles and 16 thousand words. The Huawei Basic Law clearly presents the objective, strategy, organization, human resource management, control system and formation of leadership of the company, which represents the collective wisdom of the leadership of Huawei on a series of strategically important management issues. In January 1996 all managers of the sales department were convened in the headquarters in Shenzhen for an annual retreat. In the retreat they were required to submit a personal annual report in addition to a resignation report. These managers were then evaluated and more than 30 percent of the managers were replaced by new managers who were more ambitious and energetic. This forced turnover reduced cronyism and increased professionalism of the sales department and laid foundation for the further market expansion of Huawei. Management transformation was not limited to the sales department only.

In 1998, 11 years after the founding of the company, Huawei employed more than 8,000 employees and generated USD 720 million revenue. In the same year, Huawei hired IBM consultants to guide two large-scale management transformation projects—Integrated Product Development and Integrative Supply Chain transformation. As these two projects unfolded, Huawei also invited several consulting companies to bid for consulting project to reform its financial management, as an important part of the concerted efforts in improving overall management efficiency of the company. The Klynveld Peat Marwick Goerdeler (KPMG) presented a method called "World Class Finance" in the bid and attracted the attention of the leadership of Huawei. Huawei finally chose the KPMG to undertake the project and later KPMG became the auditor of Huawei in 2000.

KPMG assisted Huawei to conduct its first management transformation project in the financial area, which is called Four Standardizations, including standardizations of the financial processes, policies, accounting subjects and control systems. In the high-speed growth period of the mid 1990s, Huawei's provincial representative offices managed their own finances. The chief representatives hired financial staff in their offices. Accordingly, the financial staff reported to the chief representatives instead of reporting to the headquarters. The weakness of this model was lack of control and monitoring by the headquarters. For instance, in several regional representative offices, such as the Hunan Office and Sichuan Office, financial staff embezzled money from the company (Peng, 2016). In addition, because of lacking standardized financial processes and accounting subjects, reimbursement and auditing processes were also very slow. It also caused difficulty in using the Enterprise Resource Planning (ERP) software that Huawei purchased from the Oracle company in 1997.

The root of the crisis-of-control lies in the decentralized organization structure that Huawei had in the mid-1990s. This structure allows Huawei to expand rapidly by offering the managers of representative offices great autonomy and incentives. However, the leadership of Huawei felt that they were losing control over a highly diversified field operation, in which managers of representative offices had authority over a broad range of issues including financial management. Freedom in this organization structure also bred a parochial attitude in the company (Xu, 2016). The solution to the decentralization problem can be establishing program of control and review for field managers in the headquarters and carefully weighing and parceling out capital expenditure across organization (Greiner, 1997). The ultimate goal of the Four Standardizations project was exactly in line with this theoretical reasoning. It aimed to strengthen the headquarters' control over front-line managers and employees to prevent corruption and misconduct, while at the same time the headquarters had authorized them to make important decisions over business activities.

To develop a set of standardized financial processes, policies, accounting subjects to form a control system, the Four Standardization project team first researched and developed the new processes and policies in the Shenzhen Headquarters. Subsequently the project team conducted a pilot project in Changsha, where financial staff once embezzled fund of the company. After the pilot project succeeded in Changsha, the process and policy was diffused to the whole company. However, the responsibilities of financial management were not taken back to the headquarters in Shenzhen once for all. They were first taken back to the regional offices which managed a large geographical area, normally encompassing several provinces. For example, the financial management responsibility in the Northeastern, Northwestern and Central China area was taken to the regional offices located in Shenyang, Xi'an and Changsha, respectively. Only two years after the reform, the responsibility was taken back to the headquarters in Shenzhen.

To strengthen financial management and control, Huawei later established accounting shared services centers. Shared services center is the entity responsible for executing and handling specific operational tasks, such as accounting, human resources, IT, legal affairs, compliance, purchasing, security and so on. Shared service centers are established for a variety of reasons, including cost reduction and service improvement, focus on core business, more control and transparency of cost, better performance of staff, elimination of redundant functions and so on (Janssen and Joha, 2006; Su, et al., 2009; Minnaar and Vosselman, 2013). Later when the integrated financial service transformation was launched in 2007, Huawei established seven global accounting shared services center, following the model and logic of establishing shared services center in China.

Huawei adopted several measures to facilitate the implementation of the Four Standardizations project. First of all, the same as in the other major management transformation projects, the CEO Ren Zhengfei is the key architect and proponent of the Four Standardizations project. Secondly, Huawei appointed the directors of the departments which are directly involved in the transformation as the project leaders. The responsibility of the transformation would accordingly fall on the shoulders of the department directors, which left them no chance but embrace the transformation. Before the Four Standardizations project was launched in 1998, many financial managers in Huawei were middle age people. The leadership of Huawei believe that these middle age managers were not equipped with state-of-the-art knowledge and had little experience with the advanced financial management. Before the Four Standardizations project, they were replaced by young managers who just graduated from universities, had no vested interest in the old system and presented no resistance to change proposed in the Four Standardizations project (Peng, 2016). Last but not the least, the gradual approach of taking the responsibility of financial management from provincial representative offices to regional offices and later to the headquarters also minimize the resistance to the transformation.

Scholars argued that routines, which is the ways of doing things in an organization, can provide a source of resistance to organizational transformation (Edmondson et al., 2001). There are multiple reasons which can explain why routines persist. The first is that learning and re-learning routines incurs cost, which leads to tendency to adhere to prevailing routines. The second is that departure from established routines provokes heightened anxieties and stakes among members of the organization, for example, between managers and workers or managers and managers. Conflict can ensue amid organization transformation. Therefore, it is reasonable to avoid organization change by sticking to the established routines (Nelson and Winter, 2002). However, research found that the people of authority, such as project and team leaders, can influence routine change by coordinating the collective learning process (Leonard-Barton and Deschamps, 1988; Edmondson et al., 2000), and stable teams may become slaves to routine and fail to respond to changing conditions (Katz, 1982). In line with these theoretical arguments, Huawei's leadership unconditional support to the Four Standardizations project and replacement of managers in the financial department ahead of the project paved way for the successful implementation.

Four Standardizations, as Huawei's first major effort of management transformation in the financial area, established the foundation for the company's sustained growth in the domestic market and subsequent expansion in overseas markets. In 2003, soon after Huawei entered overseas markets, Huawei began promoting financial standardization in overseas subsidiaries. The effort to standardize the financial system in overseas subsidiaries lasted until the beginning of IFS in 2007.

3. Background of IFS

3.1 Development of the Telecommunications Industry

By the time Huawei launched the IFS transformation in 2007, the global telecommunication industry had undergone a continuous rapid development period (ITU, 2006). To integrate the large scale of R&D resources and prepare for the fundamental change in the telecommunications industry, a series of mergers and acquisitions occurred starting in 2006. The most salient case was the Lucent Technologies and Alcatel merger in 2006, creating a company that was worth USD 36 billion and employed 88,000 individuals (IPTV News, 2006). The communications businesses of Nokia and Siemens also merged in 2006, establishing Nokia and Siemens Networks, which began operating in April 2007. By the end of 2007, the global telecommunications market was substantially consolidated. Huawei leadership witnessed this trend and believed that the consolidation of the global telecommunications industry will lead to intensifying competition and a tougher market environment for the company in later years. Huawei's top management felt it was necessary to prepare the company for the increased competition. The IFS transformation was launched not only as a measure to enhance the internal management capability but also a way to mitigate the external risk.

3.2 Operation Risks

In 2006, sales in overseas markets accounted for 65% of the total sales revenue of the company, which represents that Huawei became a truly multinational enterprise, not just a company with international business. Huawei's overseas sales increased from virtually zero in

1999 to USD 11 billion in 2007. The company successfully attracted more customers and earned more contracts outside of China. Some of these new contracts were turn-key projects which involved a significant amount of engineering work, including building towers and digging ditches. For some of these contracts, the revenues of the engineering projects were even greater than that of equipment sales. Previously it had been relatively easy for Huawei to estimate whether it would make profit from the equipment sales because Huawei produced the equipment and the company's Enterprise Resource Plan (ERP) system would clearly indicate the profitability of the equipment sales. However, it was very difficult for Huawei to calculate the costs of the engineering project. The geographical condition, labor cost and labor regulation varied greatly in different countries, which required Huawei to conduct financial management at the project level. In other words, the transformation of Huawei's business activities required transformation of Huawei financial management.

In addition, revenue recognition has also been an issue for Huawei when undertaking engineering projects. For equipment sales, revenue recognition was completed when Huawei received a Preliminary Accept Certificate (PAC) from customers after delivery. However, the delivery process in engineering projects is complex and can be a prolonged process. The financial staff at Huawei were not able to determine when the delivery was completed and when the PAC was received. Hence, they were not able to manage the accounts correctly. The variation in definition of revenue recognition caused inaccuracy in the financial data. Some business departments took advantage of this inconsistency to manipulate the financial data. Because of the weaknesses in project financial management, Huawei incurred losses with engineering projects, such as those in Brazil, Egypt and Pakistan (Peng, 2016). It became necessary for the company to take measures to contain the risk associated with engineering projects.

Another source of operation risk came from the lack of information of profitability from overseas contracts. In an internal meeting in 2007, Ren expressed his concerns: "We do receive a number of large overseas orders, but I do not know whether they are profitable" (Li, 2009). Before 2007, the role of the Huawei financial department in overseas markets was largely supportive, such as issuing audit reports. Although the Huawei financial department had already begun to conduct cost accounting in 2000, it was not involved in budgetary estimation of project. It indeed made budget, but the budget was not linked to planning of the engineering project. The financial staff did not know how to manage a profit center and had little knowledge about business processes. The financial department was more of a staff function instead of a strategic function to the company. As a result, they made errors and caused conflicts between the financial and business departments. The Huawei top management realized that if the financial department wanted to correctly estimate the accounts and profitability of the contracts, the department needed to be closely connected to the business departments. For instance, although Huawei had already had delivery project and marketing management processes in place before 2007, the involvement of financial department in the business process was insufficient and did not make the necessary impact.

3.3 Financial Efficiency

As Huawei entered more countries and gradually established its image as a credible equipment supplier, the company began to earn trust from large leading customers such as British Telecom, Telecom Italia, Mexico Telecommunications and so on. Around 2006, the value of contracts that Huawei acquired overseas became significantly larger than those obtained in the initial stage of internationalization. As the amount of purchase orders and contracts increased, Huawei began to feel cash flow pressures. The cash reserve that the company had to prepare to deliver high-value contracts presented a financial challenge. In addition, the risk associated with the possible bankruptcy of customers who signed large contracts or delayed payment also became an issue that Huawei was not able to ignore. As a result of the insufficient capabilities in financial management, the operating profit margin of Huawei dropped from 2003 to 2006 (Figure 1). In the initial stage of internationalization—for example, from 2000 to 2004—Huawei was able to use the profit earned in the domestic market to subsidize its operations in the international market. However, approximately in 2005, as the volume of its international sales surpassed that of the domestic market, Huawei stopped using this strategy; it became obvious that the company needed to transform its financial system to sustain further growth.

（Insert Figure 1 Here）

4. The Second Financial Transformation Project–Integrated Finance Services

To address the financial management challenge, in 2007, Huawei CEO Ren Zhengfei wrote a letter to Samuel Palmisano, the then-CEO of IBM, and asked whether IBM would be able to help Huawei transform its financial system to improve the company's processes and management (Li, 2009). Different from the process of selecting the KPMG to undertake the Four Standardizations project, Huawei did not invite other companies to bid for the project this time. Huawei only invited IBM mainly because IBM helped Huawei transform its product development and supply chain management. The leadership of Huawei realized that because the product development, supply chain and financial management are inter-related, it would be more effective to consult IBM to connect financial system to the business process which IBM had helped transform, than to seek advice from other companies (Peng, 2016). Ren Zhengfei admired IBM for its management system and expertise which sustained its business development for more than a century. He believed that the most valuable asset of Huawei is its management system established and improved through a series of large-scale transformation projects. He wanted Huawei's management system could play a role similar as IBM's in the company development (Huawei, 2016c). Palmisano accepted Ren Zhengfei's invitation, and the IFS transformation began in 2007.

The “Integrated” in Integrated Financial Services indicates that the transformation aimed to connect the financial and business departments, including R&D, marketing, sales and supply chain management and so on. “Finance Services” means that the financial department would provide services to the business departments. If the Integrated Product Development can be observed as a management transformation project to link R&D and marketing and sales, IFS can be considered a project to improve the synergy between the financial and business departments. Its implementation can be divided into two stages: IDS I and IDS II. In both stages, IFS consisted of dozens of sub-projects that were carried out in parallel.

4.1 IDSI（2007-2011）

IDS I began in 2007 and ended in 2011. The main purpose of the transformation at this stage was to connect the financial and business departments. It was expected that the connection would enhance the accuracy of the financial reporting or, in other words, correct the account information. In the IDS I stage, the IFS transformation consisted of a number of major projects. We introduce the Opportunity to Cash, Procurement to Payment, Shared Services Center and Information Technology projects in detail due to the limited space.

Opportunity to Cash (OTC): The main purpose of this cross-functional project is to connect the financial and business departments to address the revenue and payment confirmation issues and expedite cash flow into Huawei. Four new policies were adopted in the OTC project to meet the project objective. First, the contracts were standardized. The basic elements of the contracts, payment conditions and delivery process were clarified. Second, credit management was carried out throughout the process of fulfilling the contract. The solvency of a customer was examined before signing contract, each delivery and installation of equipment and payment. In this new process, the credit of the customer is evaluated and recorded systematically in Huawei’s financial system, which will provide reference for future business relationship with the customer. Third, the delivery and invoicing process was optimized. It was decided during the implementation of OTC project that delivery by Huawei should generate invoicing by the customers. Therefore, in the new process, the Huawei employee who delivers equipment to the customers should write report and submit to the customer. According to the contract, upon receiving delivery report, the customer should invoice Huawei. Fourth, the systematic management of accounts receivables was established. For example, the measures were defined to address the customers’ concerns to facilitate their payment.

We use a standardized contract as an example to illustrate the concrete measures that were adopted in IFS. The standardization of contracts was the solution recommended by the OTC project team to tackle the issue of revenue recognition discussed in Section 3.2. It is suggested that the revenue recognition be clarified in the contracts. If Huawei was not responsible for equipment installation after delivery, according to contract, revenue recognition would then occur upon delivery. If Huawei was responsible for equipment installation as well, revenue recognition would occur after the installation was finished.

As an important measure to expedite the cash inflow to Huawei, the OTC project team recommended adopting the concept and measures of Minimum Delivery Unit (MDU) and Minimum Payment Unit (MPU). Before IFS was implemented, the payment for a typical contract of Huawei was always divided into several stages, including, for example, one payment after the contract is signed, one payment after the first delivery, and so on. As discussed in Section 3.1, however, the value of the contracts that Huawei earned in the overseas market had increased substantially in around 2006. Therefore, the account receivables increased substantially as well. This posed a risk for Huawei's operation and became a challenge that the IFS needed to address. The IBM consultant and Huawei IFS team generated a solution, which was to define the MDU and MPU of a large contract and use them to divide up the large contract. For example, for the Private Branch Exchange product, before the MDU and MPU principle was adopted, pricing was based on plate which includes various parts. In line with the new principle, pricing became based on smaller units, that are parts. With smaller units of delivery and payment, Huawei's operation risk was significantly reduced (Fan, 2016).

Procurement to Payment (PTP): This project aimed to improve the management of purchase orders and payments to suppliers and strengthen the connection between the financial and procurement departments. The system established in the project reminded Huawei staff members to pay suppliers in a timely manner, therefore helping Huawei establish an image as a credible partner. The system also reminded suppliers to issue invoices to Huawei on time. The improved management of purchase orders and payments to suppliers contributed to a healthy ecosystem surrounding Huawei. In addition, this project connected the procurement and payment processes, which ensured the accuracy of the procurement data and helped Huawei strengthen internal control. Before the project was implemented, the procurement department had a full say in choosing suppliers and the certification of suppliers. After the implementation, the financial department became involved in the process, which reflects the Huawei leadership's long-lasting view that financial department should be able to play a controlling role when the business developed rapidly.

Shared services center: The goal of this project was to establish accounting shared services centers across the world following successfully setting up similar centers within China when implementing the Four Standardizations project. A pilot project was conducted in Malaysia before the project rolled out to the rest of world. By 2009, seven accounting shared services centers were established. They were located in Argentina for the Americas; the United Arab Emirates (Dubai) for the Middle East; Romania, Poland and the UK for Europe; Mauritius for Africa; and Malaysia for the Asia Pacific region (Fan, 2016; Peng, 2016). Different from the shared services centers of other multinational corporations whose functions are to save on costs and improve efficiency, the sharing centers in Huawei were more actively engaged in central accounts, cash management and, importantly, acting as a centralized control center.

Information technology: The management tools based on the IT system are deemed by Huawei critical for the successful implementation of management transformation projects because once the new processes were defined, the staff needed to use new tools to implement the processes. This project aimed to develop management tools based on the IT system. The Process and IT Department of Huawei which employed several thousand staff was deeply involved in this project. A couple of dozens staff from this department worked closely with the staff from the financial department to co-develop an architecture of the IT system to facilitate implementing the new financial and business processes. The financial staff and IT staff were also the core members of the IFS change management project which is discussed below.

4.2 IDS II （2010-2013）

IDS II started in 2010 and ended approximately 2013. The primary objective of IDS II was to define the responsibility center and implement financial management at the project level. It was decided during the IDS II stage that the regional markets and product lines are both responsibility centers. However, regional markets are primary responsibility centers, but the product lines are secondary centers. The delivery and supply chain departments were defined as cost centers. Other departments were defined as expense centers. IDS II also included dozens of projects. Here, we introduce two sub-projects as examples: Reporting Analytics and Project Financial Management.

Reporting Analytics (RA): The primary tasks of this project were twofold. The first is to clarify the responsible departments and the cost and expense centers, respectively. Huawei established profit centers in 2006. Afterward, every product line claimed itself as a profit center. However, the financial management was not sufficiently effective to calculate the profit and loss of each product line. In 2010, it was decided in the IDS II stage that Huawei should establish a true responsibility center. A question immediately emerging in the discussion was whether a regional market or a product line should be considered a responsibility center. Both offices (departments) wanted to be considered a responsibility center, but only one could be the primary responsibility center. The final decision was that regional markets are primary responsibility centers and product lines are secondary centers, based on the argument that staying customer-centric is the core value of Huawei and that the regional market is closer to the customers than the product line.

Another question being clarified in the Reporting Analytics project is whether the manufacturing department and supply chain management department can be considered profit centers. In the initial discussion, these two departments proposed to become profit centers. However, the proposal was rejected by the Huawei leadership because if there were too many profit centers established in the company, conflicts would ensue among them. A hypothetical case is that when a contract is signed, the revenue would be separated by product lines if each of them acts as a profit center. As long as one of these centers is not satisfied with its share in the total revenue, it would reject the contract that would be otherwise valuable for the company as a whole. With this reasoning, the Huawei leadership decided to establish the manufacturing department as the cost center, and from then, they only needed to be concerned with the cost savings.

Project Financial Management (PFM): The project is a crucial step to upgrade Huawei's financial management capability. After the project was implemented, project became the basic unit of management of the Huawei company and project team became the basic organization of the company. Huawei was able to discern which project was profitable and thus greatly reduced the operation risk and enhanced management efficiency. There are three major differences between the project financial management before and after the PFM project was implemented. First of all, before the implementation, the budgetary estimate of project was done by sales department only. In order to earn a contract, the sales department often produced a budgetary estimate which demonstrated profitability of the project. However, the outcome could be the opposite. This caused the problem documented in Section 3.2 that Huawei leadership actually did not know which overseas project, particularly those involving engineering work were profitable. After the PFM was implemented, the budgetary estimation was conducted according to customer's proposal jointly by the sales department and financial department, which increases creditability and accuracy of the estimate. The Huawei leadership stated clearly in 2011 that "all Chief Financial Officers should participate in evaluation of contract and they should dare to veto the low-quality contracts" (Huawei, 2016c). Secondly, the actual budgeting was done previously by financial department only after the contract was awarded. After the PFM was implemented, budgeting was connected with the Statement of Work of the project, planning and execution of the project. Financial department and business departments were jointly responsible for budgeting. Last but not the least, the final accounts were done for project after the PFM implementation to indicate whether the project was profitable and why. Then the final accounts were used to guide the next budgetary estimate.

5. Promotion of IFS

IFS was complex and involved many different departments in the company. Before the new processes were rolled out to the whole company, the IFS project team usually conducted pilot project in a regional office or product line. The only difference between the practice in the pilot project and that later diffused to the whole company is that the new IT systems were yet developed during the pilot project. Except for the IT system, the processes, policies and standards implemented in the pilot project are the same as in the late company-wide implementation. The pilot projects were normally undertaken for two to four months. As long as the IFS project team deemed the new processes, policies and standards worked as expected, the new practice were rolled out to the whole company, accompanied with new IT systems (Fan, 2016).

However, as “growing by self-reflection” has become the core value of the Huawei company and the company has invested billions of dollars into management transformation projects in other areas before the IFS started, there has been a consensus among the Huawei leadership that the only unchangeable in the world is the change itself (Fan, 2016; Huawei Company, 2016c). Nevertheless, after the transformation was gradually rolled out, it received considerable resistance from the business departments, which experienced difficulty in adapting to the new processes that were suggested by the IFS project team. CEO Ren Zhengfei explicitly supported the IFS project, saying, “IFS is a company-wide transformation that not only aims at the finance system. Every top leader of the company should be involved in the IFS. If there are departments that think they can transform without support from the project team, I will think the departments can generate profit without expenses. Then the leaders of these departments will not be promoted. In the IFS transformation, the financial department should not close its door either, thinking without involving and consulting business departments” (Huawei, 2016c). Ren’s strategy to implement IFS was similar to implementing the IPD: “First, copy it exactly, then refine and fix it.”

Huawei paid a great deal of attention to designing and implementing new processes, creating new organizations and making and disseminating new IT tools in the IFS project, which are deemed the key outputs from the management transformation projects in Huawei (Fan, 2016). Regarding the new organizations, a Financial Transformation Steering Committee was created to oversee the IFS project. The members of the Steering Committee included the leadership of Huawei, such as Guo Ping, the then-Chief Legal Officer; Hu Houkun, the then-Chief Sales and Service Officer; and Liang Hua, the then-CFO of Huawei. Guo Ping was the chairman of the Steering Committee. Three of them decided on the important issues for IFS and reported to Ren Zhengfei. Approximately 300 people were involved in IFS. More than 200 people were from Huawei, who formed the project team of Huawei. Approximately 60 people were consultants from IBM. At the company level, the Project Management Office was established to oversee the activities of the sub-projects and coordinate the efforts from these sub-project teams. The project team meetings were held about every two weeks. Usually 20 to 30 people attended the meeting, including the IFS Project Management Office staff, the leaders of various sub-projects and CEOs of various departments (Fan, 2016; Peng, 2016). In the bi-weekly IFS project team meetings, the leaders of various sub-projects had to report on the progress of the projects that they led. If the progress did not match the expectations, the project leaders faced tremendous pressure and possible dismissal after the meeting (Peng, 2016).

（Here Insert Figure 2）

Change Management, which is a project integrated in IFS, played an important role in promoting IFS. The project team was composed of six to seven people. Its main task was communicating with the business departments and promoting IFS transformation in the company. Because IFS involved many functional departments, the Change Management team's burden is particularly heavy because it had to discuss and convince these various departments of the benefits of IFS.

IT tools are used to facilitate the new process and implement the IFS transformation. For example, before e-mail was developed and widely used, Huawei contracts were signed as hard copies. After e-mail became popular, the hard copies of contracts were scanned and transmitted. In both cases, contracts were sometimes lost in transmission. In the IFS transformation, a contract management IT system was established. All the contracts were uploaded to the system. Anyone in the company who needed to have access to the contract could do so easily by logging into the system. A similar system was created for purchase orders. From signing contracts, placing orders, planning, and manufacturing to delivery, all processes could be reviewed in the system by anyone involved in them. These IT systems improved the connection between different departments and enhances efficiency and facilitated the implementation of new processes and organizations that were established in the IFS transformation.

6. IFS Benefits

IFS benefited Huawei by helping Huawei improve its overall financial management capability and financial performance, and also addressing its particular financial problems. As demonstrated in Table 1, before 2010, Days Sales Outstanding (DSO) and Inventory Turnover (ITO) was very large; after 2010, they both decreased, which means that the cash turnover and speed of inventory turnover became quicker than ever. Huawei saved about USD 4.95 billion because of inventory management improvements. Furthermore, when Ms. Wanzhou Meng, CFO of Huawei, presented the Huawei annual report 2014, she emphasized that continuous management transformation, including IFS, improved the profit level of the company. Through various measures of risk control, bad debt has been dramatically reduced, which increased profit by USD 28 billion in 2015 (Hu, 2016).

(Insert Table 1 Here)

There are a large number of particular financial problems that were addressed in the IFS project. Due to the limitation of the space, we use only the inaccuracy of financial data as an example to illustrate the transformation's impact. In the period 2007-2008, the financial data generated from the profit centers were usually inconsistent, which generated significant conflict between the business departments and the financial department. Because ensuring the accuracy of the financial information is the main goal in the IDS I stage transformation, by 2010—when the IDS I was finished—the conflicts between the financial and business departments dramatically decreased. Sporadic complaints of incorrect data have appeared, but this has not been a major issue since 2010. Internal customer satisfaction had greatly improved with regard to the accuracy of the financial data (Fan, 2016). Before 2010, manipulation of financial data existed because the revenue recognition was not clearly defined. Through the implementation of the Opportunity to Cash project, Huawei gradually solved the problem by standardizing the contracts and defining revenue recognition. After 2010, manipulation of financial data by business departments became rare.

7. Financial Management of Huawei

The other aspects of the Huawei financial management such as financing and investment were not the focus of the two abovementioned major financial management transformation projects. However, they indeed contributed immensely to the success of Huawei. We briefly discuss them in this section.

7.1 Financing

Equity financing, that is issuing stocks to the employees, has been a major channel of raising capital since Huawei's foundation. Debt financing was only supplementary (Peng, 2016). Huawei established its Employee Stock Ownership Plan (ESOP) in 1990, three years after founding of the company. The objective of the ESOP is described in the Article 17, Chapter 1 of the "Huawei Basic Law", as that "we let employees become shareholders to form the core of the company and maintain control over it in order to sustain its growth. … We implement the Employee Stock Ownership Plan. The program on the one hand lets the model employees who agree with the company's core value bond with the company and on the other hand makes the most responsible and capable employees the core members of the company" (Huawei, 1998).

The ESOP in Huawei went through several following reforms in the last two decades. Huawei allowed employees to obtain dividends based on their shares in 1997, introduced virtual stock options and phased out the original ESOP model in 2001, introduced cap for the maximal stock purchase amount for individual employees to reserve stock-purchase opportunities for new employees in 2008, and launched a Time-based Unit Plan to allow the all employees, particularly foreign employees, to share the profit of the company, which is similar to the virtual stock options (Zhu et al., 2013; Yan, 2014). All these reforms did not change the major functions of the ESOP program, that is motivating and incentivizing employees and raising capital. It was reported that from 2004 to 2011, Huawei raised RMB 27.5 billion from the two shareholders of the company, the Union of Huawei Investment & Holding Co., Ltd and Ren Zhengfei. In 2011 only, Huawei raised RMB 9.4 billion from its shareholders. In the same year, Huawei total borrowings (including long-term and short-term borrowings) increased only RMB 7.4 billion (Huawei, 2012). Compared with its competitor, the amount of fund that Huawei has raised from its employees is substantial. Since its listing in the Shenzhen stock exchange in 1997 and Hong Kong stock exchange in 2004 till 2011, ZTE raised only RMB 2.4 billion and HKD 2.1 billion from the two exchanges, respectively (Caijing, 2012).

Scholarly studies have demonstrated that ESOP can boost the productivity of the companies (Kumbhakar and Dubar, 1993; Jones and Kato, 1995) because employee ownership can produce favorable employee attitudes and behaviors (Pierce et al., 1991; Pierce et al., 2001). Feelings of ownership are also accompanied by a felt responsibility and a sense of burden sharing of the organization, which leads to heightened level of employee motivation (Druskart and Kubzansky, 1995; Kubzansky and Druskart, 1993). The leadership of Huawei considered the ESOP is the most critical factor of Huawei's success because the plan ties up employee and the company's interests, motivate and incentivize employees and realize the core value of the company, that is, inspiring dedication (Xu, 2016).

7.2 Investment

Scholars have suggested that a primary function of the headquarters of a Multinational Enterprise (MNE) is to run its internal capital market which can effectively re-distribute resources within the firm (Stein, 1997; Lamont, 1997; Mudambi, 1999). The headquarters in the MNEs can create value by actively reallocating scarce funds across projects. The cash flow generated by one division's activities may be taken and spent on investment in another division, where the returns are higher (Stein, 1997). MNEs can also leverage the internal capital market to move the resources from mature, profit-generating units or markets to young fast-growing units or new markets, as young units or business are crucial for a company's sustainable development, though they usually have difficulty in making profit in the beginning (Mudambi and Navarra, 2004; Mudambi and Swift, 2014).

Huawei leveraged its internal capital market. It clearly distinguishes profitability requirement for the mature and young businesses. The profitability and operation efficiency of the mature businesses are required to increase every year. In contrast, young businesses are allowed to incur loss. When Huawei makes annual budget, loss for the young businesses is often budgeted in. If the young business makes less loss than what is budgeted in in a year, it would be considered superior performance. Huawei also differentiates the profitability threshold for core business and non-core business. For the core business which is strategically important for the company's sustainable growth, even if Huawei incurs loss in the business, the company still supports its development. However, for the non-core-business, the Huawei company will collect 16.7% of the revenue from the business unit as the operation cost. This means that the business has to have higher than 16.7% profit rate in order not to be closed down by the leadership of Huawei (Peng, 2016).

Different from the theory and practices in many companies that the scarce fund is reallocated to the projects according to their returns, Huawei allocated fund to the projects which did not necessarily bring higher returns, but had to be the core business of the company. Even the projects were profit-losing, as long as it was related to the core business, it could receive continuous financial support from the headquarters. This practice ties up Huawei's investment strategy closely with the company's strategy and reflects the founder and CEO Ren Zhengfei's long-held view that Huawei's financial management should not only support business growth and expansion, but also control for risk and supervise business activities.

8. Conclusion

In this chapter, we document the first large-scale financial management transformation that Huawei has implemented—that is, Four Standardizations and the subsequent, more ambitious transformation Integrated Financial Services. Huawei carried out these two projects with the assistance of external consultants from KPMG and IBM, respectively. We analyze the background of the transformations, the motivation of the Huawei top management in implementing these transformations, major projects and activities, and their impact.

We find that the success of the Huawei financial transformation is largely due to three key outputs of the projects, including new processes, organizations and IT tools, which are assigned significant importance by the project team. The new processes were generated from the standardization of the existing but repeated activities, which were instrumental to improving management efficiency and reducing operation costs. New organizations were created to implement the transformation. The staff in these new organizations planned, designed and executed the processes and discussed and coordinated with the involved business departments. New IT tools were developed to facilitate the implementation of the new processes, which are key to disseminating new practices and routinizing new processes. The three key elements combined contribute to the success of the financial transformation at Huawei.

The financial management problems that Huawei encountered in the course of growth and internalization and the solutions that it adopted to mitigate the problems can be explained by the classical financial management and international business theories. However, Huawei's financial management clearly possess its unique features. For example, financial management is strictly dominated by the overall business strategy. Investment decision is not made by comparing the returns of various projects, but based on the strategic importance of the projects to the core business of the companies. This strategy has not changed since the foundation of the company. Financial department has to play a supportive role in business development, but importantly also serves as monitor and controller of business development. These principles together with the fact that Huawei is a private company wholly owned by its employees and the Employee Stock Ownership Plan was used as a means of raising capital for the company can explain why the abovementioned two major financial management transformation projects did not focus on financing and investment decision processes of the company but on its financial accounting processes.

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Table 1: Days Sales Outstanding (DSO) and Inventory Turnover (ITO) of Huawei, 2008-2015

Year	DSO	ITO
2008	127	110
2009	125	100
2010	95	92
2011	88	73
2012	90	60
2013	109	64
2014	95	104
2015	84	96

Source: Annual Reports of Huawei (2008-2015)

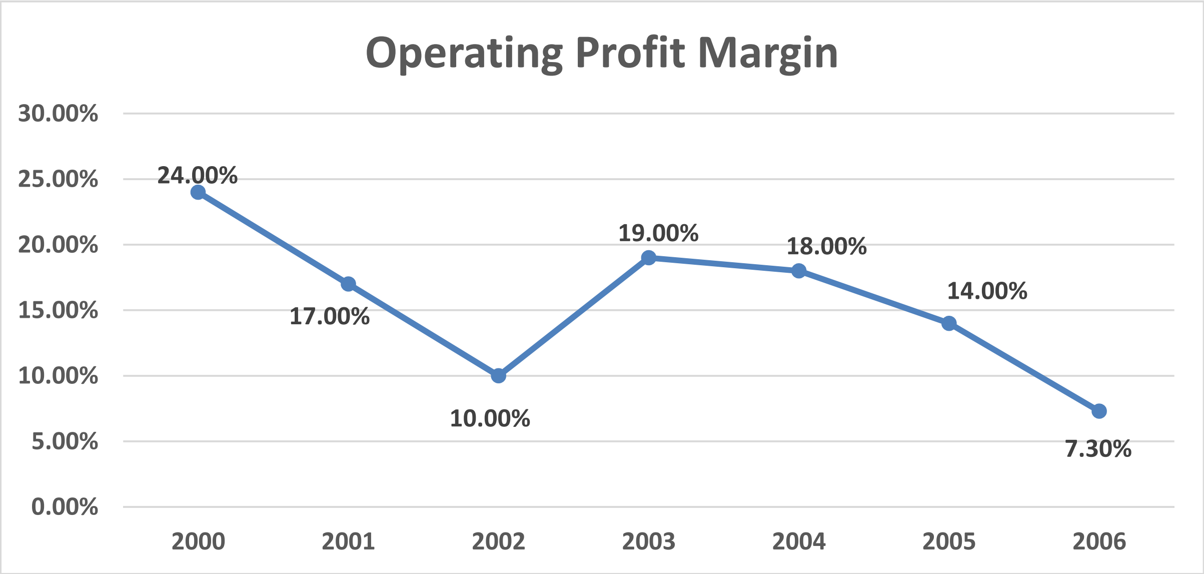

Figure 1: Operating Profit Margin of Huawei 2000-2006
Source: Annual Reports of Huawei 2000-2006

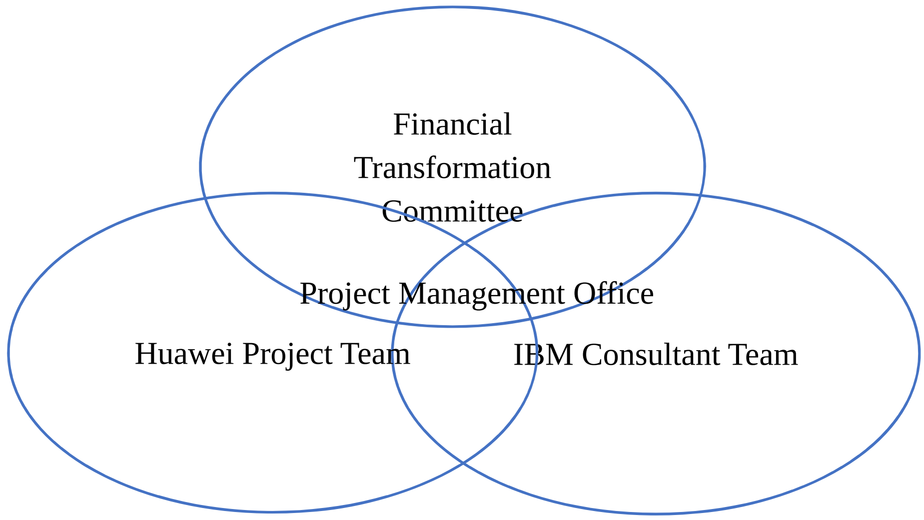

Figure 2: The Relationship of Four Teams in IFS
Source: Organizational Transformation of Huawei

Collaboration behaviors in the development of telecommunication standards: a perspective of patent network analysis

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Keywords: telecommunication standards, patent network, collaboration behavior

Abstract

Industrial standards aim at ensuring equal access to the technology for all stakeholders, and telecommunication industry is a highly standardized industry. This paper examines collaboration behaviors in the development of telecommunication standards using patent network analysis, that is, if more than two companies co-declared a patent to 3GPP, we view that there is one collaboration tie between each couple among them. By giving each company a tag, we managed to find several typical kinds of collaboration behaviors (e.g. parent-subsidiary; technology-law; etc.) Furthermore, by comparing the network graphs, we can figure out the transitions of companies and countries across three generations of telecommunication standards.

So far, the telecommunication industry has gone through 4 generations of technical standards, namely from 1G to 4G. Standard essential patents (SEPs) are patents that are indispensable in order to manufacture a product or offer a service based on the standard in question. To conduct network analysis, we follows several steps. At first, we retrieved the SEP data of 3GPP[1] standards from the online database of ETSI and then after manually cleaning, filtering and matching them with external patent database, we finally got an informative dataset which contains SEPs (or potential SEPs) of 2G GSM, 3G WCDMA and 4G LTE. Then we wanted to divide the SEPs into three parts according to the project identifiers (e.g. GSM: 'GSM'; 'GPRS'; etc.), however, we found that there are a large proportion of SEPs belonging to more than one standards, as a result, all SEPs are classified into seven categories. In order to explain the exiting overlapping area among the three standards, we proposed two possible mechanisms, which are, "durable old ideas" and "compatible new ideas". Based on the above-mentioned classification work, we do the analysis and get some implications for the industrial stakeholders.

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Modelling ‘Green’ Paracetamol Supply Chain Operations Defined by Renewable Chemical Feedstocks in England: A System Dynamics Analysis

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Abstract

The aim of this research is to provide a first-effort System Dynamics (SD) model that effectively captures the operations and market dynamics across the entire ‘green’ paracetamol supply chain (SC) defined by terpenoid feedstocks. To that end, we first describe the particular ‘green’ analgesic SC system arising from renewable chemical feedstock platform technologies, as envisioned to be established in England. Following, the associated SD model is developed by capturing all related operations, namely: (i) turpentine supply, (ii) primary – active pharmaceutical ingredient – manufacturing, (iii) secondary – pharmacy dosage form – manufacturing, (iv) packaging, and (v) retailing where demand is defined based on both the patients’ actual needs and the environmental awareness of a potential ‘green’ analgesic market. The obtained SD simulation results reveal the need to promote ‘green’ pharmacies to support circular SCs of the future and to elaborate green marketing practises to increase the associated stakeholders’ profitability in environmentally sensitive markets.

Keywords: Circular supply chains; ‘Green’ paracetamol; Pharmaceutical supply networks; Renewable chemical feedstocks; System Dynamics.

1. Introduction

In the 21st Century, transition from fossil-based feedstocks to renewable alternatives is a key challenge stemming from the depletion of natural resources (Rodríguez, Arias and Rodríguez-González, 2015) and the increased environmental awareness of consumers (Aivazidou et al, 2016a). Indicatively, 62 % of 250 business executives declared that sustainable corporate investments are motivated by the expectations of consumers for ‘green’ products (Accenture, 2012). Consequently, the emerging pressure for ‘green’ business offerings has considerable ramifications to sustainable manufacturing and supply chain (SC) management (Maniatis, 2016).

In a similar context, the United Nations Millennium Development Goals Target 8.E prompts the pharmaceutical industry to provide patients with equitable access to essential medicines that are clinically efficient, environmental friendly and cost-effective (United Nations, 2015). Therefore, pharmaceutical companies tend to adopt a “benign by design” approach to manufacture sustainable pharmacies in a way to reduce impact and effluents to the environment (Leder, Rastogi and Kümmerer, 2015), while contemporarily retaining or even improving the medications’ pharmacological properties (Kümmerer and Hempel, 2010). To that effect, the environmental performance of national healthcare systems could be improved as well (Leder, Rastogi and Kümmerer, 2015) considering that these systems comprise a major clientele of pharmacy procurements globally (Ryan-Fogarty, O'Regan and Moles, 2016). Indicatively, the carbon footprint of England's National Healthcare System (NHS) is estimated to be 22.8 Mt CO_2-eq., 6.5 % of which is attributed to the procurement of pharmaceuticals (Sustainable Development Unit, 2016).

However, the development of pharmaceuticals SC theory and practise defined by value-added renewable chemical feedstocks is mainly hindered by: (i) the reliance of the industry on vertically integrated petrochemical feedstock supply systems (Lamers et al., 2015), and (ii) the lack of research upon the technical feasibility of renewable chemical feedstocks' exploitation for medical applications (Behr and Johnen, 2009). Therefore, an evident need for a modelling approach that captures the 'green' pharmaceuticals SCs' structure arising from renewable chemical feedstock platform technologies to support the networks' sustainability assessment and commercial viability analysis exists (Bam, 2014).

The aim of the present study is to effectively model the dynamics of operations across a 'green' pharmacy's SC defined by renewable chemical feedstock platform technologies and to further investigate the impact of consumers' environmental awareness on the SC's commercial viability. More specifically, we investigate the case of 'green' paracetamol, synthesised from terpenoid feedstocks, to cover the demand for this particular analgesic in England. Paracetamol (also known as acetaminophen and by its chemical name, (N-(4-hydroxyphenyl)acetamide) is an active pharmaceutical ingredient (API) which is widely used to manufacture non-steroidal analgesic medicines. In England, paracetamol is among the most prescribed medicines by the NHS, contributing circa 21 % by quantity of API (Penny and Collins, 2014). At a global scale, the estimated average consumption of acetaminophen is 100 tonnes per annum with a projected market value of USD1.0 billion (201.2 ktonness) by 2022 (Transparency Market Research, 2015). Furthermore, our study focuses on this particular pharmaceutical product due to our collaboration with leading European Chemicals SC businesses and academic stakeholders in the context of the Engineering and Physical Sciences Research Council (EPSRC) funded project "Terpene-based Manufacturing for Sustainable Chemical Feedstocks" (EPSRC Reference: EP/K014889/1). To this effect, we first adopt the System Dynamics (SD) methodology in order to capture and monitor the SC operations of a 'green' paracetamol SC in England, from a cradle-to-grave perspective. Secondly, we investigate the effect of various market behaviours in the relation between Green Image Factor (GIF) and relevant market share and SC stakeholders' revenues to motivate efficient policy interventions. In fact, SD is a simulation-based tool for analysing the dynamic behaviour of complex systems that has been proven to be useful in strategic policy-making (Roberts, 1978; Sterman, 2000).

The remainder of the paper is organized as follows. In Section 2, we provide a brief literature review about pharmaceutical SCs. Following, in Section 3 we develop a SD modelling framework that captures the SC operations for 'green' paracetamol in England, while further investigating the impact of various GIF-related market behaviours in corporate performance, in case renewable chemical feedstocks are exploited. In Section 4, we briefly elaborate on the results of the system's performance and the derived economic value. Section 5 concludes with managerial insights and directions for future research with respect to green marketing strategies for the sustainable growth of the pharmaceuticals sector within a circular economy era.

2. Literature Review: Pharmaceutical Supply chains

The extant literature on SC sustainability in the pharmaceutical sector is rather limited. In this section we provide a short review of selected studies attempting to study the sustainability concept in pharmaceutical SCs. Our literature review reveals the absence of comprehensive theories and modelling approaches on the field, while the case of 'green' pharmacies defined by renewable chemical feedstock platform technologies is evidently unexplored. The only existing works for the design and management of circular SCs in the pharmaceutical sector, arising from renewable chemical feedstocks, are provided by Tsolakis, Kumar and Srai (2016) and Settanni, Tsolakis and Srai (2016). Table 1 presents a synopsis of the reviewed state-of-the-art research efforts including the research nature and the methodology applied at every study.

Table 1. Sustainable pharmaceutical supply networks' selected literature.

Reference	Research Nature	Methodology
Hansen and Grunow (2015)	Quantitative	Two-stage stochastic mixed-integer linear programming
Mousazadeh, Torabi and Zahiri (2015)	Quantitative	Bi-objective mixed-integer programming
Rusnac et al. (2012)	Quantitative	Simulation
Sousa et al. (2011)	Quantitative	Mixed-integer linear programming
Srai et al. (2015)	Qualitative	Four-stage theoretical analysis of an end-to-end supply network
Uthayakumar and Priyan (2013)	Quantitative	Operations research non-linear modelling approach for inventory management
Weraikat, Zanjani and Lehoux (2016)	Quantitative	Non-linear mathematical programming

Hansen and Grunow (2015) provide a two-stage stochastic model to support market launch preparation decisions in pharmaceutical SCs, focusing on the balance between time-to-market and risks. Additionally, Mousazadeh, Torabi and Zahiri (2015) provide a modelling approach for supporting strategic decision-making in the development of robust pharmaceutical SCs while contemporarily tackling issues of epistemic uncertainty. Furthermore, Rusnac et al. (2012) identify important economic, environmental and social criteria to assess the sustainability performance of pharmaceutical downstream logistics and further study the impact of the related operations on the decentralised and centralised configurations of both decision-making systems and physical network structures.

Furthermore, Sousa et al. (2011) optimise the net profit of a global pharmaceutical SC, from primary and secondary production sites to product distribution and markets by applying spatial and temporal decomposition algorithms for a portfolio of medications. In addition, Srai et al. (2015) develop an approach for evaluating the potential SC benefits deriving from the transition from batch to continuous manufacturing for pharmaceutical products. Uthayakumar and Priyan (2013) develop an operations research model for determining optimal solutions for inventory lot size, lead time, and the number of deliveries for multiple pharmaceutical products in order to achieve hospital customer service level targets with a minimum total cost for the SC. Moreover, Weraikat, Zanjani and Lehoux (2016) study a pharmaceutical case and examine the proactive role of stakeholders' coordination and negotiation interactions to ensure efficient and sustainable reverse SCs in the sector.

3. A System Dynamics Modelling Framework

In this section, a novel modelling approach for managing the operations in 'green' pharmaceutical supply networks arising from renewable chemical feedstocks is developed, merging: (i) the theory of SC mapping, and (ii) the theory of SD, which has a proven track record for tackling strategic decision-making problems. In particular, we provide a pilot analysis of the dynamic behaviour of the supply, manufacturing, packaging and market operations across a prospective 'green' pharmacy's SC. We consider the illustrative conceptual case of 'green' paracetamol dispensed in England, as motivated by our participation in the aforementioned EPSRC funded research project "Terpene-based Manufacturing for Sustainable Chemical Feedstocks". The latter project aims to develop a sustainable, integrated platform for the manufacturing of industrial chemicals based on biological terpenoid feedstocks to complement carbohydrate, oil and lignin-based feedstocks that will be available to sustainable chemistry-using industries of the future.

In this context, a SD modelling framework is proposed that could be employed by public stakeholders in England responsible for renewable materials' waste management as a strategic decision-making tool for potentially exploring the impact of several policies tailored to the exploitation of wasted teprenoid feedstocks in the national chemical industry. The primary objective of the model is to capture the related SC operations that would foster the understanding of 'green' pharmacies' networks defined by renewable chemical feedstocks, as dictated by the contemporary circular economy era ramifications. On a secondary level, the model would provide long-term estimates of 'green' paracetamol demand in England in order to assist the strategic planning of the potential pharmaceutical industry segment. Below, the system under study is described in brief and the associated SD model is developed.

3.1 System description

We study the SC of a single pharmacy, namely 'green' paracetamol, while we consider that the shelf-life of the product extends the period of analysis. 'Green' paracetamol is assumed to have the same pharmacological properties as conventional paracetamol. We also assume a monopolistic environment, in which all stakeholders are located within England, thus considering no delays in the distribution operations of the supply network. The pharmaceutical SC includes the following echelons of SC operations: (i) renewable chemical feedstock supply, (ii) primary manufacturing where the API is produced, (iii) secondary processing where the API is processed into the pharmacy's dosage form, (iv) packaging where medication dosage forms are manufactured into packages to be dispensed to the market, and (v) retailing where demand is defined based on the patients' needs and the consumers' environmental sensitivity stemming from the utilisation of renewable chemical feedstocks for the API formulation. The conceptual system under study is illustrated in Figure 1 via the relevant causal loop diagram. Causal loop diagrams are used to capture the mental models which managers conceive of a system. In a causal diagram, arrows describe the causal influences among the variables of the system (Sterman, 2000). Typically, each arrow is assigned a polarity that indicates the relation between dependent and independent variables. A positive (+) polarity denotes that the effect changes towards the same direction as the cause (reinforcing feedback). On the other hand, a negative (-) polarity denotes that the effect changes towards the opposite direction of the cause (balancing feedback).

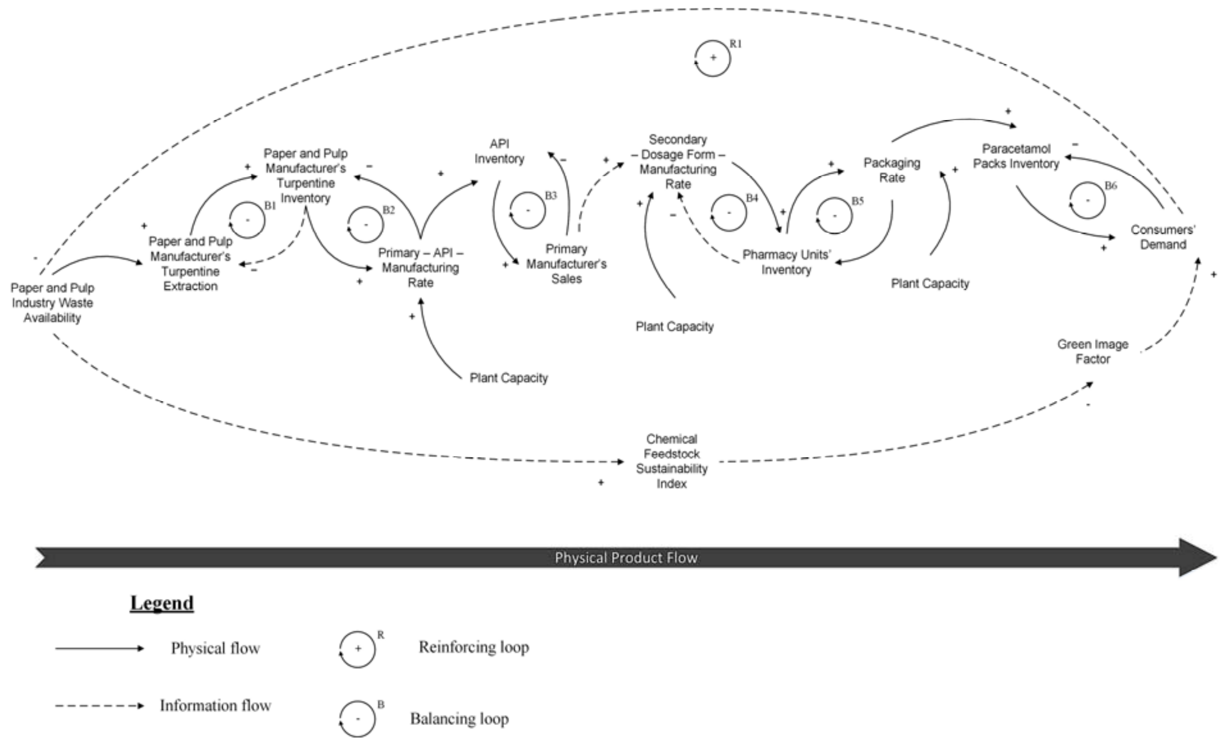

Figure 1. Causal loop diagram of the system under study.

3.1.1 Renewable chemical feedstock supply

Typically, pharmaceuticals are produced using inefficient batch reactors and wasteful stoichiometric processes from unsustainable petrochemical feedstocks. On the other hand, the scope of the refereed project is to demonstrate the safe and large industrial scale synthesis of paracetamol from the renewable monoterpene feedstock β-pinene. However, β-pinene is further extracted from crude sulfate turpentine (CST) (Jung et al., 2016; Mercier, Prost and Prost, 2009) that can be recovered as a by-product during the pulp digestion in a Kraft paper mill (Roberge et al., 2001; Yumrutaş et al., 2008). Unfortunately, CST is always contaminated with high concentrations of sulfur which must be reduced prior to its utilisation. Key applications of crude sulfate turpentine are summarised in Table 2.

Table 2. Applications of crude sulfate turpentine [Adopted from CBI (2015)].

Market Segment	Applications	Benefits
Cosmetics	Disinfectants and cleaning agents	Adding pine odour
Fragrance	Use in fragrance diffusers, incense products, candles, and aroma-therapeutic oils	Adding fragrance
Food	Flavouring	Adding flavour
Painting Industry	Cleaning agent	Solvent for paints and varnishes

Therefore, in order to promote independence of the national chemical industry, in this study we only consider the pulp available from the paper and pulp industries in the United Kingdom. The Confederation of Paper Industries (CPI) is the leading organisation aiming to unify the United Kingdom's paper-based industries with a single purpose in promoting renewable and sustainable practises to the sector aiming to enhance the competitiveness of its members. The 45 listed paper and pulp mills in CPI account for a total nominal pulp production capacity equal to 4,149,500 tonnes per annum (CPI, 2016). Notably, for the specific chemical synthesis route of 'green' paracetamol API that we consider, chemical pulp and specifically crude sulfate turpentine is recommended as input. Furthermore, we do not assume that the extracted CST from the paper pulp presents any seasonal availability patterns.

3.1.2 Paracetamol primary manufacturing

Regarding the paracetamol primary manufacturing stage, a single manufacturer procures CST from domestic paper and pulp mills geographically allocated across the United Kingdom. During the primary processing stage, the renewable chemical feedstock is converted into acetaminophen, while the manufacturing rate is limited by the processor's production capacity level. More specifically, two major components of CST, namely α- and β-pinene (available in concentrations of about 30 % and 60 % respectively), can be isolated from the crude material and have extensive applications in solvents, resin precursors, pharmaceutical intermediates and commodities (Nie et al., 2014). According to the advancements in the chemical synthesis routes developed within the context of the participating research project, we consider that paracetamol API is synthesised by the renewable chemical feedstock β-pinene extracted from CST. In order to satisfy the market demand, the retailer holds his own inventory, while he places turpentine orders to paper and pulp mills in order to avoid disruptions in the manufacturing process. Pharmacy API is transported directly to a single paracetamol secondary manufacturer.

3.1.3 Paracetamol secondary manufacturing

The secondary paracetamol manufacturing stage focuses on the production of the pharmacy's dosage forms (Meneghetti et al., 2016). We assume that the manufacturer produces only solid state dosage forms of paracetamol including tablets, capsules and suppositories. However, the secondary manufacturing output is considered homogeneous in terms of volumes and categorisation among the different dosage forms is contemplated. Paracetamol dosage forms are then stored in the secondary manufacturer's warehouse and are further forwarded to the packaging manufacturing stage. We deem that secondary manufacturing and packaging are performed at the same plant, but in different production lines. Therefore, transportation costs and time delays are negligible.

3.1.4 Packaging

During the packaging phase, packages of paracetamol dosage forms are produced and complement the secondary manufacturer's stock. The packaging rate is limited by the processor's production capacity level. Only a single packaging is considered as we do not consider any market segmentations in the present pilot study.

3.1.5 Demand

Demand for paracetamol is expressed as packs of dosage forms and is considered stochastic, estimated by historical data about the dispensed paracetamol quantities in England during the period 2013-2016. Particularly, the demand function was estimated based on NHS publicly available statistics for the paracetamol quantities (in dosage units) dispensed by: (1) pharmacy and appliance contractors in England, and (2) dispensing doctors and dosage units supplied under personal administration. Furthermore, we consider that consumers are environmental sensitivity towards the sustainable nature of the offered medication. Concerning the supply chain's economic performance analysis, we only considered the turpentine's procurement price, following a stochastic pattern based on historical data, and the price per package of paracetamol.

3.2 Model development

The system is modelled using the SD methodology in order to capture the causal loops and feedbacks that attach dynamic behaviour to the system. The core concepts of SD are feedbacks, causal loop diagrams, and stock and flow maps: (i) feedback loops and structures are fundamental because they capture the real patterns or modes of systems' behaviour as they dynamically evolve over time, (ii) causal loop diagrams assist modellers in representing the feedback structures of a system, and (iii) stocks provide the system with memory, thus enabling the disequilibrium dynamics in systems (Sterman, 2000).

3.2.1 Renewable chemical feedstock supply

Initially, to estimate the availability of renewable chemical feedstock, we model the supply of chemical pulp in the United Kingdom. Therefore, following data available by FAO (2014), the paper and pulp mills in the United Kingdom account for a total chemical pulp production capacity equal to 10,000 tonnes per annum. Furthermore, we assume that the availability of chemical pulp follows an annual declining trend with stochasticity as indicated for the case of domestic wood pulp (Eurostat, 2016). We assume that this capacity refers entirely to CST that is valorised and used as the renewable chemical compound to produce acetaminophen. Typically, 0.5 to 15 kg of turpentine are extracted per tonne of pulp. Assuming a fixed turpentine extraction rate of 6 kg per tonne of pulp as suggested by Kuenen (2013), the monthly available turpentine volumes are simulated. Following the trend in the United States of America, we assume that 20 to 25% of the available turpentine is used in the flavour and fragrance industries (Mattson, 1984). We further assume that a corresponding 25 to 30% of CST is attributed to cosmetics and painting industries. Therefore, we accept that the remaining CST could be dedicated exclusively for the production of paracetamol. Due to the nature and the expected high quality specifications of the end-product, in this study we assume that a purification processing of CST is also conducted that results in 80 % of purified CST (Yumrutaş et al., 2008).

3.2.2 Paracetamol primary manufacturing

Asia Pacific is the largest producer of paracetamol API due to the presence of a large number of local manufacturers with an estimated 30 % lower manufacturing cost (Transparency Market Research, 2015). Presence of advanced manufacturing facilities, cheap and abundant labour, developed infrastructure, availability of wide range of raw materials and intermediate products are driving paracetamol production in China. Together, China and India-based manufacturers produce about 115,000 tonnes of paracetamol API per year, equivalent to about 70 % of the global market. In Europe, no paracetamol API manufacturer is documented, while the last Western paracetamol API manufacturer is Covidien Ltd. located in Massachusetts, United States of America, with an annual production capacity of 30,000 tonnes (Vinati Organics Limited, 2016). Nevertheless, in our modelling approach we consider a single paracetamol API manufacturing plant with a typical capacity of 10,000 tonnes per year. We also assume that turpentine is instantly supplied to the primary manufacturer from domestic paper and pulp mills, in case a deficit is observed.

3.2.3 Paracetamol secondary manufacturing

Paracetamol API is almost instantly transported to a secondary manufacturing plant by trucks. We consider that the single manufacturing plant can produce all the commercial paracetamol dosage forms of 500 mg, i.e. capsules, tablets and suppositories. Based on our secondary research on pharmaceutical plants, we assume that the annual capacity of the secondary paracetamol manufacturing facility is 800 million units. The plant has available space for holding an inventory of 100 million units per month. After the manufacturing process, all the available capsules are forwarded towards the packaging manufacturing stage.

3.2.4 Packaging

In the packaging stage, the provided dosage forms are manufactured into packages of 16 units dedicated for domestic consumption. Based on corporate reports, the available warehouse capacity for the manufactured paracetamol packages is estimated to be 45 million packs.

3.2.5 Demand

In order to estimate the demand for paracetamol dosage forms of 500 mg, we elaborated publicly available data from the NHS Business Services Authority for the period 2013 to April 2016 (NHSBSA, 2016). Particularly, we retrieved data for the dispensed units of 500 mg paracetamol dosage forms, i.e. capsules, tablets and suppositories, across England (Figure 2).

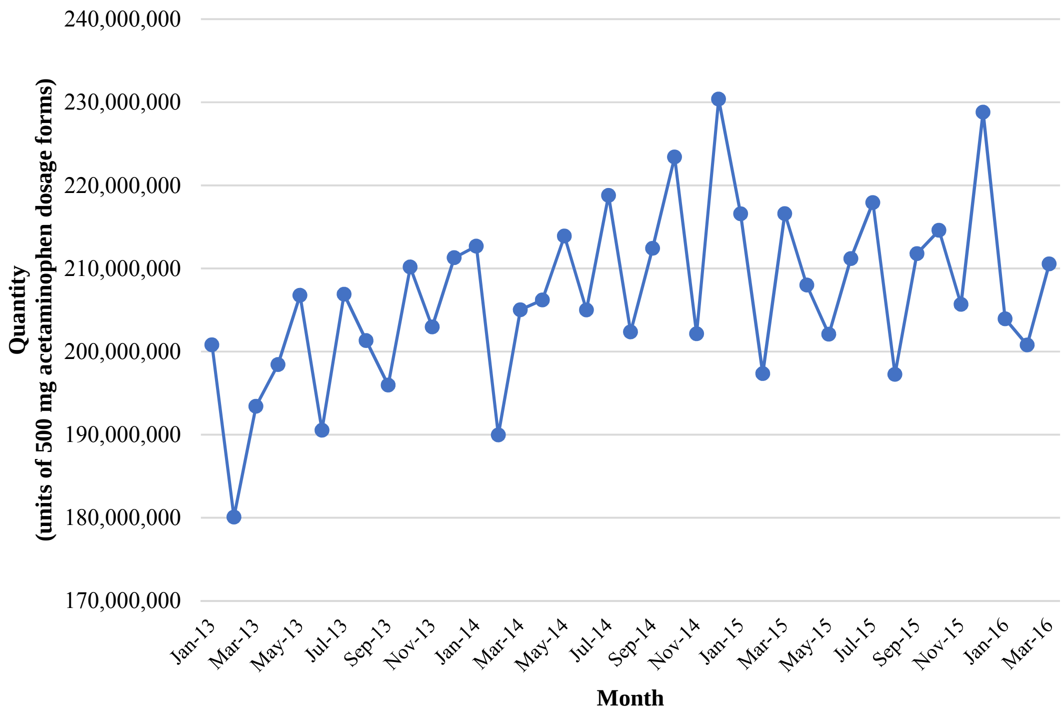

Figure 2. Monthly units of 500 mg acetaminophen dosage forms dispensed across England, 2011-2016 [*Source*: NHSBSA (2016)].

Following an initial statistical analysis of the data set and considering that the data points consist a time series that presents a trend, we model and forecast the monthly acetaminophen 500 mg dosage units as a time series with stochasticity for up to five years (or sixty months) ahead using three appropriate benchmark models (Nahmias, 2008), including: (i) naïve forecasting, (ii) simple linear regression, and (iii) Holt's double exponential smoothing. More specifically, based on the findings of Nikolopoulos et al. (2016) for the case of generic drugs, we apply a 70 % drift on the naïve forecasting method, where the drift equals the difference between the last known actual observations. Following, we compared the performance of the elaborated projecting methods based on three characteristics of the forecasts (Makridakis and Hibon, 2000), namely: (i) bias – measured through the mean error (ME) to unveil any systematic tendency to over- or under-forecast the actual demand, (ii) accuracy – evaluated through the mean absolute error (MAD) to determine the closeness of the forecasts to the actual values, and (iii) uncertainty – assessed through the mean squared error (MSE) to identify the magnitude of the average deviation of the forecasted values from the mean forecast. Table 3 shows the forecasting performance of the elaborated forecasting methods. The results suggest that the most appropriate method for making a 5-year ahead forecast for generic paracetamol is Holt's double exponential smoothing.

Table 3. Long-term forecasting horizon: ME, MAD and MSE of generic acetaminophen.

	Naïve forecasting	**Linear regression**	**Holt's exponential smoothing**
ME	-140,714.75	0.00	941,293.26
MAD	17,768,583.84	7,310,082.67	1,817,064.64
MSE	442,395,786,402,591.00	83,202,535,035,395.60	5,384,869,918,684.90

Furthermore, we assume that demand is defined by the consumers' environmental sensitivity concerning the nature of the paracetamol raw material. As illustrated in Figure 3, the consumers' ecological awareness is modelled through the GIF concept which represents a percentage change in demand (Georgiadis and Vlachos, 2004). Following the studies of Georgiadis and Besiou (2008) and Aivazidou et al. (2016b), we adopt the GIF concept and hence we consider three different market behaviour scenarios as follows: (i). consumers are not environmentally aware with regard to 'green' paracetamol resulting in zero GIF (No Environmental Sensitivity), (ii) consumers are environmental aware and GIF is expressed as a linear function (Linear Environmental Sensitivity Pattern), and (iii) consumers are environmentally sensitive and exhibit an S-curve shaped GIF (Logistic Function Environmental Sensitivity Pattern). We hypothesise that GIF is affected by the chemical feedstock sustainability index (CFSI), a conceptual index related to the nature of the elaborated feedstock for the manufacturing of the offered value-added intermediate or end-product. For example, in case petrochemical feedstocks are elaborated for the production of paracetamol, then the CFSI is assumed to be assigned a value above 1. On the other hand, as in the case of 'green' paracetamol the CFSI is less than 1 as a renewable feedstock is used as the main manufacturing input; hence the consumers' demand increases due to positive GIF values and vice versa. As the chemical synthesis route of 'green' paracetamol discussed here is not yet finalised and stabilised for industrial scale production, it is not able to accurately calculate established environment impact metrics across the entire SC (e.g. CO_2 emissions).

Therefore, we assume that CFSI follows a stochastic pattern with a mean value of 0.5 and a standard deviation 0.1 for the three different market behaviour scenarios.

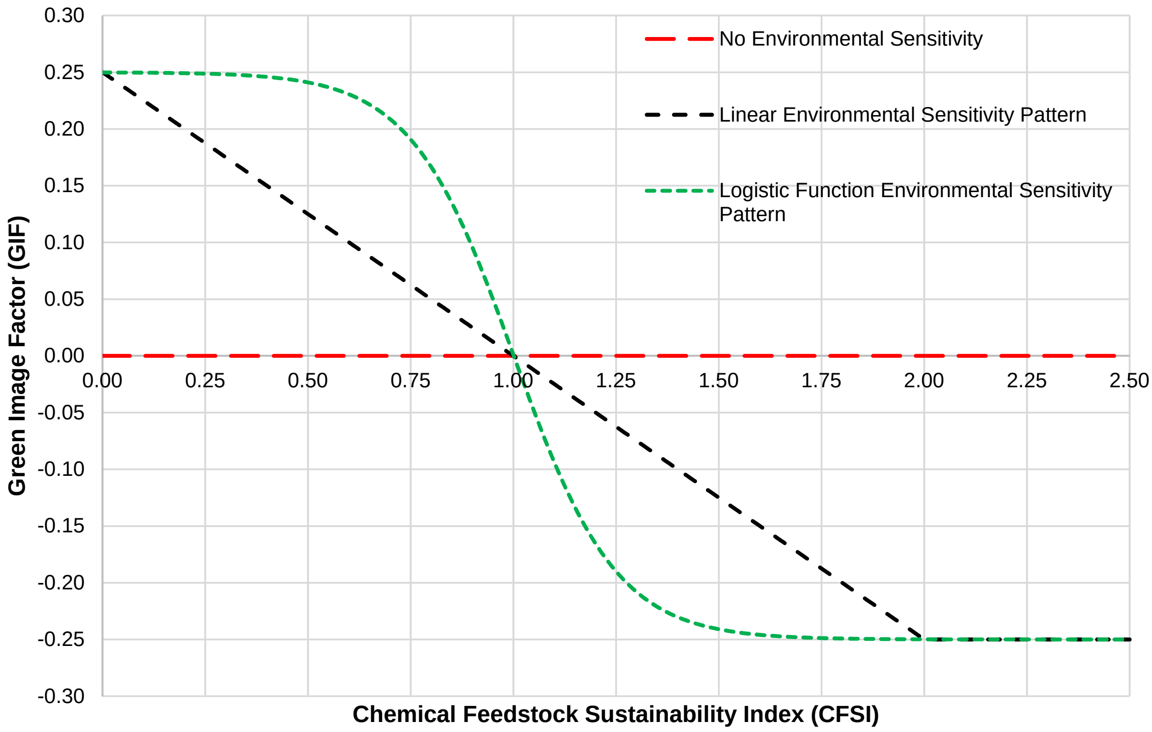

Figure 3. Environmental behaviour of consumers [Adopted from Aivazidou et al. (2016b)].

3.3 Economic assessment

Based on a statistical analysis of historical data about turpentine price, we forecast its price through a linear regression model (R^2 = 0.92) with stochasticity. Finally, the price per pack of paracetamol is considered to be £ 0.55, following the corresponding price of branded paracetamol packs currently available in market.

3.4 Model validation

The developed SD model was tested regarding its validity and reliability, and it was further verified against its structure and functionality. Specifically, a series of tests was elaborated in order to assess the performance of the proposed system. These tests include (Sterman, 2000; Toka et al., 2014): (i) verification of the data used as input, (ii) sensitivity analysis of the model behaviour against changes in the parameters of the system, (iii) rational interpretation of the model simulation results for different sets of parameters and outlier values, and (iv) comparative analysis and evaluation of the derived results for a variety of conceptual scenarios.

4. Simulation Results and Discussion

The applicability of the proposed SD model is demonstrated through the case of 'green' paracetamol production. To that end, realistic quantitative estimates associated with manufacturing and demand across the paracetamol SC are adopted from secondary sources and grey literature. A strategic horizon of five years (or sixty months) is selected in order to capture the market dynamics with regard to consumers' environmental sensitivity, while the time step is set to one month. As the model includes stochastic variables, we conducted a 1,000 simulation runs to derive more realistic and accurate results. The model code was generated using the simulation programming language Powersim™ 10.

In our simulation, as stated previously, we considered three different market behaviour scenarios, namely: (i) Scenario #1 – no environmental sensitivity, (ii) Scenario #2 – linear environmental sensitivity pattern, and (iii) Scenario #3 – logistic function environmental sensitivity pattern. Scenario #1 is the base case scenario meaning that it is used as a benchmark for comparing the simulation results obtained for all the scenarios. The metrics used are the demand for 'green' paracetamol (in # of paracetamol packs), market coverage (in %) and revenues for the 'green' paracetamol market (in % increase) in England. Figure 4 summarises the observed average values of the aforementioned metrics over the period 2016-2021.

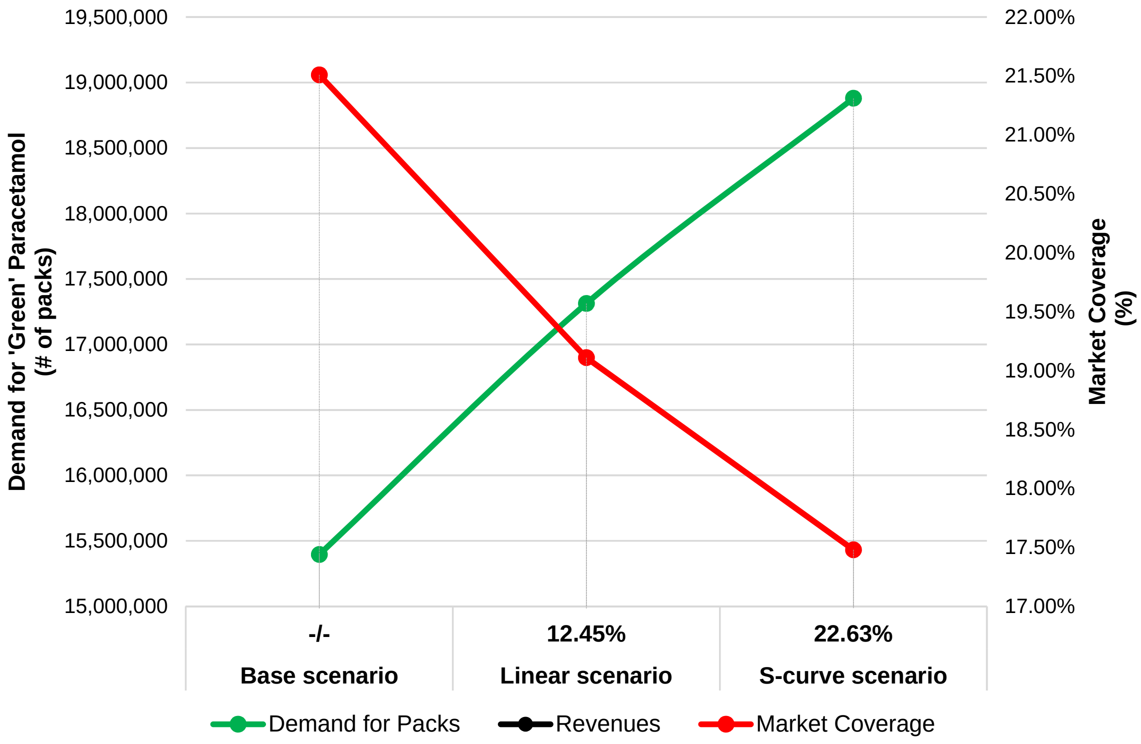

Figure 4. Simulated performance metrics for the 'green' paracetamol SC under study in England, 2016-2021.

The simulation results indicate that with the current assumptions made, domestic 'green' paracetamol production could cover about the 21.50 % of the English market demand for dosages of 500 mg of acetaminophen. In addition, in environmental sensitive markets demand for 'green' paracetamol packages of 500 mg (16 units per package) is expected to increase by 9.10 to 12.50 % corresponding to an increase in projected revenues by 12.45 to 22.63 %. Evidently, the utilisation of renewable chemical feedstocks to substitute petrochemical raw materials in environmentally sensitive markets could significantly increase the revenues of SC stakeholders due to the consumers' demand growth. A major bottleneck that hinders the capturing of greater economic value is the limited installed primary manufacturing capacity.

5. Conclusions

A generic finding from our brief literature review on the pharmaceutical SCs' sustainability reveals that the extant research efforts are mainly limited to forward and reverse logistics operations (Narayana, Elias and Pati, 2014), neglecting the potential of exploring circular supply network opportunities on the sector. To this effect, in this manuscript we propose a first-effort SD model for capturing the operations and market dynamics across a 'green' analgesic's supply network defined by terpenoid feedstock platform technologies. The applicability of our modelling approach is demonstrated through the case of 'green' paracetamol defined by β-pinene, as targeted by EPSRC to be developed in England. Specifically, our modelling approach investigates the manner in which various market behaviour patterns affect corporate performance according to pharmacy's CFSI, in case renewable chemical feedstocks are utilised. Firstly, the simulation results document that England could cover a considerable market demand for paracetamol through exploiting the nationwide available chemical pulp wasted from domestic paper and pulp mills. Secondly, sustainable feedstocks in environmentally sensitive markets could promote circular supply networks and eco-friendly pharmaceutical products, thus enhancing business financial performance.

A key limitation in the present modelling approach refers to the assumptions about the primary 'green' paracetamol manufacturing capacity as the related chemical synthesis route is not yet stabilised and demonstrated, even in a laboratory environment. Furthermore, market segmentation based on the provided paracetamol dosage forms has to be further considered as manufacturing capabilities could change significantly among the different dosage forms of the pharmacy. Additionally, since the chemical synthesis route of 'green' paracetamol is not yet finalised, the present modelling approach may inadequately capture the functions of the corresponding actual system. The CFSI has to be estimated by the accumulated environmental impact of all operations across the 'green' paracetamol SC so that the GIF is estimated in a more transparent manner. 'Green' paracetamol may be in fact produced from renewable chemical feedstocks; however, the material inputs during the primary manufacturing stage of 'green' paracetamol may have a greater environmental impact compared to the inputs used for the manufacturing of conventional paracetamol. Cost estimates should be considered for all SC operations as well.

As regards future research, focus should be placed on the stimulating role of green marketing techniques upon consumers' environmental sensitivity (Aivazidou et al., 2016a). In order to exploit the proposed SD simulation tool, it is suggested that marketing specialists should further study the application of green labelling and branding in pharmaceutical products for guiding consumers towards green purchasing decisions.

Acknowledgments

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Interdependence Dynamics of Business Ecosystem: The Case of the Chinese Rare Earths Industry

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Abstract

This paper proposes interdependence dimensions and patterns for inter-organisational relationships. It uncovers how interdependence effects on strategic decision making of the firm, how interdependencies are being managed to realise value creation, and how this interactive process changes the entire business ecosystem. We have adopted multiple case study methods, focusing on the Chinese rare earths business ecosystem. By investigating the whole industry and its related value networks, we are able to elaborate the dynamics of interdependence and business ecosystem transformation in a shifting industrial landscape.

Keywords – inter-organisational interdependence, business ecosystem, rare earths industry, value creation, strategy making

Introduction

The term "business ecosystem", initially introduced by Moore (1993), has been prevalently explored in the field of strategic management. In analogy to the natural ecology, the business ecosystem is naturally associated with ideas of networks, interdependencies, and co-evolutionary thinking. Drawn from existing research, inter-organisational interdependencies are seen as one of fundamental nature of business ecosystems. In business world with highly uncertain future, firms and their behaviours are inevitably interdependent with various organisations and activities. More and more corporate decisions have been made beyond "input-output" thinking, with ecosystem perspectives instead. There are not only be seller-buyer or supplier-customer relations, but a network of multiple sides' relationships constitute a complex economic community. In other words, the business ecosystem does not stress dyadic transactions, whereas it features polyadic interactions and constellations of value creation. In this sense, the dynamics of organisational interdependence is a crux to understand the nature of business ecosystems. This paper aims to uncover how interdependence affects strategic decision making of the firm, how interdependencies are being managed to realise value creation, and how this process changes the entire business ecosystem.

We focus on business ecosystems of the Chinese rare earths industry in this research. It is an industry that relates closely to a large number of modern industries, due to the unique chemical and physical properties of rare earths. In the past decade, the high-tech applications of rare earths, particularly in low-carbon technologies, have emerged and expanded rapidly with robust expected demand (British Geological Survey, 2011). With few substitutes, rare earths are processed to be key components of high-end products, ranging from electronic devices such as mobile phones, computers and semiconductors, to aerospace engineering such as jet engines and defence systems, as well as indispensable use in clean energy and environmental technologies, such as fuel cells, wind turbines, electric vehicles and pollution scrubbers. The rare earths industry in China, on the whole, is transforming from mainly resource-based processing to more technological applications. It is one of the fastest changing arenas, which incorporates a variety of business opportunities into the themes of advanced resource utilisation and environmental technologies.

Wide applications and ongoing innovations lead to higher value creation. With the increasing recognition of potential resource value, rare earths manufacturers have gradually emerged, diversified and co-evolving with related industries, associations and institutions, etc. Different organisations have contributed to the expansion of rare-earth-based business ecosystems, becoming influential players in the actual interaction. The dynamics of interdependence among those ecosystem players can be traced and analysed in the rare earths industry and its closely linked activities. Their interdependences are not merely a status or precondition of business ecosystems, but they change along with multi-organisational strategic renewals and ecosystem-level interactions. This is also a case in point to elaborate the mechanisms of interdependence in a shifting industrial landscape.

Business ecosystem and interdependence

Moore (1996) defines the business ecosystem as “an economic community supported by a foundation of interacting organisations and individuals—the organisms of the business world”. It sheds light on inter-relationships and co-evolution of organisational interactions and overall business environment. Since Moore, there have been various research in strategic management encompassing the business ecosystem. Those studies share common grounds in terms of constructs and configurations: (1) Players of the ecosystem include all kinds of stakeholders at different levels including suppliers, customers, governments, associations and institutes, etc., forming networked interdependencies. (2) These players are interconnected and interdependent on one another, co-evolving over time. (3) Players provide mutual benefits, create joint value or exert influences in the business ecosystem. (i.e. Chang & Uden, 2008; Iansiti & Levien, 2004; Iansiti & Richard, 2006; Gueguen et al. 2006; Moore, 1996; Rong, 2011)

Concerning ecosystem players–different species in the business ecology, Iansiti and Levien (2004) categorised four types of participants, including the keystone player, the niche player, the dominator and the hub landlord. This is a relatively static configuration as the category of players has not revealed the role varying process and value sharing or shifting. To solve the adoption problem, a wide-lens toolbox was proposed to reconfigure the structure of interdependence and leverage advantage within and across ecosystems (Adner 2012). This may help to examine co-innovation risks between inter-organisational collaborations. However, most research concentrates on firms, rather than other species such as research institutes, industry associations, and government agencies or regulatory organisations. We fill this void by proposing poly-adic interactions of multiple different types of organisations. In our cases, rare-earth firms find ways to mobilise external resources by interacting with other players in the business ecosystem. They realise resource value and industrial development with the help of other ecosystem players.

In order to map out inherent mechanisms of the business ecosystem, we need to interpret inter-relationships of those key species first. Linkages of different organisations are embedded in interdependent activities, which include joint projects, mutual commitments, and different forms of alliances and communities such as strategic cooperation partners and joint ventures. We elaborate the interdependence based on these interactive activities, rather than static descriptions of each links. Decomposing interdependence from an ecosystem perspective helps revealing the nature of business ecosystems.

Interdependence is an inter-disciplinary theory that has been discussed in the field of economics, sociology, and organisation theory, etc. The study of interdependence among firms' activities builds on the long tradition in evolutionary economics of exploring how challenges to identifying profitable sets of productive activities can lead to intra-industry heterogeneity and provide a nuanced understanding of how competition evolves over time (Lenox et al. 2010). Intrinsically, interdependence reflects the extent of competitive and symbiotic nature of relationships (Pfeffer and Salancik, 2003). Its effects are not only identifiable in practice but also analogous in magnitude to the effects of other environmental aspect (Vagnani, 2015).

On the Web of Science database, there have been over 900 academic papers about interdependence in business and management studies to date, but the vast majority of research is about intra-organizational interdependence. Applying interdependence theory to the study of intra-organizational process is consistent with organizational rationalities that ask for internal adjustment and coordination (Cheng, 1983; McCann & Ferry's, 1979; Thompson, 1967; Weick, 1979). On the other hand, inter-organisational interdependence refers to the tightness of coupling (Orton & Weick, 1990) and the level of mutual commitment between partners (Leonard-Barton, 1995). Various interdependence frameworks have been used to represent the intensity and complexity of alliance relationships in general (e.g., Contractor& L orange,1988). In highly uncertain contexts, causal ambiguity exists in the process of resource exchanges among organisations and their social networks. Interdependence becomes a managerial issue for strategy makers: How to manage complex interdependencies of multiple levels with dispersed ecosystem players.

Among extant varieties of descriptions on interdependence, workflow and resource interdependencies are the two representative formations. No matter it is a pooled, sequential or reciprocal pattern (Thompson, 1967), or asset, task and technology interdependence, they are belonged to either workflow or resource interdependence, or a mix of both. However, it is not sufficient to explain how these interactions effect on the business ecosystem and vice versa. We therefore attempt to integrate interdependence and business ecosystem into one framework, and delineate interdependence dynamics by analysing strategic renewal and industrial transformation.

Research methodology

This research adopts the case study approach, as it is mainly to answer the question of 'how' rather than linear causalities (Yin, 1994). As inter-organisational interdependence of business ecosystems is not a well-established theory, we choose to conduct exploratory research

(Eisenhardt,1989; Yin, 1994). With a philosophical position of social constructivism, we look at the Chinese rare earths industry and its value networks. On the one hand, the number and scale of rare earth companies and related organisations are limited over the world, so it is unlikely to gather a large enough sample for the hypothesis-deduction analysis and mathematical modelling. By contrast, however, the case pool seems too large and too complex for a cricalist to carry out reflexive actions, as the objective world involve numerous high-tech industries with scientific and technological speciaties. Only constructivism provides an appropriate base for this research. On the other hand, social constructivism has the advantage to explain the whole picture and all settings of people and groups, not statistical as positivists while not sceptical like criticalists. By repeated, persistent observation and interpretations of the stakeholders, not only can this research map the rare earth industry and its business ecosystem as a whole, but also retain the complexity and richness of the inter-relationships among ecosystem players.

The unit of analysis is the interdependent activity. Interdependent activities include joint projects, mutual commitments, and different forms of alliances and communities such as strategic cooperation partners and joint ventures. Our case entities include all key ecosystem players, ranging from leading rare earths manufacturing firms to their related organisations, such as industry associations, R&D centres and product exchange platforms.

Data is collected in the form of multiple on-site investigations, one-to-one semi-structured interviews and formal group meetings, supplemented by participatory action research lasting ten years. In-depth data mainly came from interviews. We interviewed top managers, chief engineers, finance directors, head researchers, and policy makers at multiple levels. The selection of interviewees was based on whether the person has significant influence on strategy making and interdependence change. Each interview took 1 to 2 hours. We strictly followed the "24h rule" to transcribe all interviews within a day (Eisenhardt,1989). We cross-checked the facts by interviewing different staff and managers in different departments. In addition, with the assistant of Wechat group, some insider groups such as rare earths application forums and environmental alliances are assessable in real time. Meanwhile, we make full use of public documents such as government policy reports, patent information, annual reports of listed rare earths companies, and trading statistics from different sources, etc. In our longitudinal studies, we have conducted multiple case qualitative analyses and formed insights of interdependence dynamics of the rare earths ecosystem. Our assumption is that firms can gain additional resources from their business ecosystems, and they form appropriate strategies to realise resource value based on inter-organisational interdependence. Following this logic, we tend to capture strategy forming processes at each stage of industrial development. Our research questions focus on how interdependence effects on corporate strategy making, and how this transforms the business ecosystem.

Case study analyses and discussions

In the fast changing rare earths industry, firms tend to manage interdependence from an ecosystem perspective. As an interdependent activity normally involves several organisations in action together, we need to figure out main players in each project first (Table 1). Inducting from our case studies, we are able to summarise interdependence patterns along two dimensions.

We adapt a framework from project interdependencies by Newell et al. (2008). Interdependent activities can be seen as a matrix of ecology and interactivity. Different ecology levels indicate whether the business ecosystem has simple or complex configurations. It shows how many "species" co-exist, and time, space and type of organisations involved in the same ecosystem. On the interactivity dimension, it illustrates how interdependencies are managed across activities. Interdependent activities can be exemplified by all kinds of programs surrounding the rare earths industry (Figure 1).

Table 1 Key Players Identification

Case	Number of key players	Duration of decision making (year)	Complexity	Level of interactivity
MRI joint venture	6	2 (It took two years to decide the cooperative project)	Complex	High
TJ pilot test base	5	1	Complex	High
Baotou product exchange	12	1.5	Complex	Low
Aerospace co-project	3	0.5	Simple	Low
Fujian alliance	3	1	Simple	High
Jiangxi alliance	10+	5	Complex	Low
Permanent magnet network	17	3	Complex	High

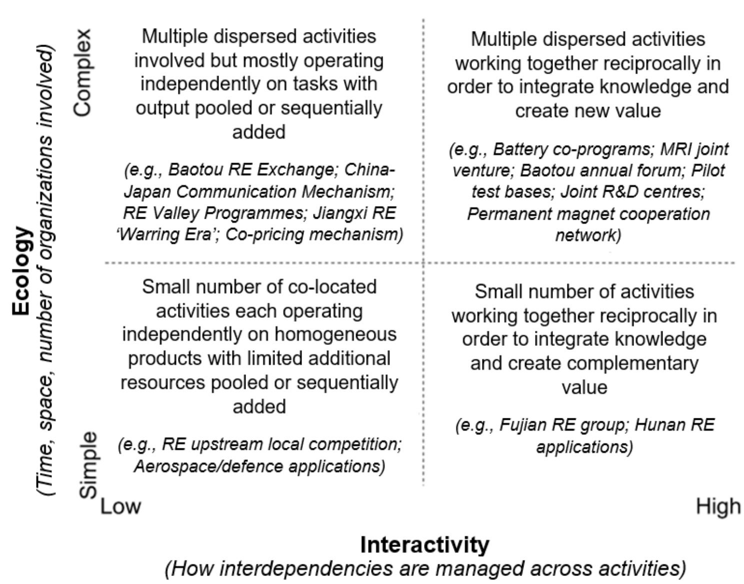

Figure 1 Interdependence Pattern

According to our case studies, four propositions can be proposed for further analysis. We do not divide interdependent activities merely by positive and negative interdependence, but combining business ecosystem perspectives to complete the typology (Figure 2).

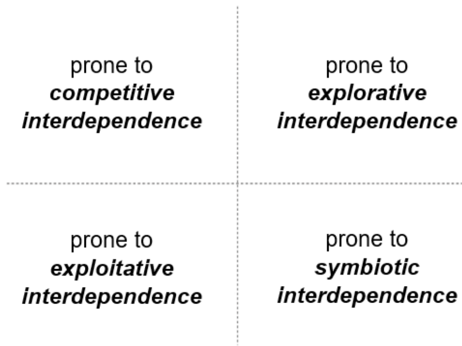

Figure 2 Interdependence typology

Proposition 1: Interdependent activities with high degree of interactivity and complex ecology features are prone to be explorative interdependence. Cooperative projects and innovations are more likely to occur in this context.

The most typical explorative activities are led by Company A – the largest rare earths producer in China and the world. At the beginning of value nurturing, Company A tended to invest multiple joint ventures in rare earth applications with Western companies. The Corporation ROB is a typical subsidiary in this respect. It was originally a China-U.S. collaborative project, producing intermediate components for electric vehicles, including high-power MH-Ni batteries, battery plates, and hydrogen storage alloys. Three American companies and one Chinese company signed the collaborative contract. In order to solve technical problems, A evolved the Japanese Company S to join in the project at a later stage, which helped updating the equipment of automatic nickel-hydrogen battery assembly line.

Instead of foreign joint ventures, Company A has been seeking domestic collaborations more recently. For example, it enables catalyst projects to be established with its strategic co-operative partner— the Corporation SC. As rare earths have various potentials to be used in catalyst materials, the two corporations connect the upstream and downstream value chain, while developing new applications of rare earth-based catalysts co-operatively. Also, this decision is based upon the fact that A produces a large number of Lanthanum (La) and Cerium (Ce) compounds, due to the ore composition in Baiyun'Ebo Mine. The prices of La and Ce raw materials are comparatively lower than the rest of rare earth elements, whereas abundant resources of La and Ce elements can be useful in catalytic technologies, promoting energy efficiency and benefiting the environment. In this sense, it is more profitable for the corporation to move up the value chain into catalytic applications, rather than selling raw materials directly. The cooperation decision making occurred on a national rare earth industrial forum, which provided a platform for multiple sides to negotiate business opportunities.

With regard to cross-industry interaction, Company A has prioritised medical equipment to expand its value network. It has helped nurturing the Corporation XB in the Rare Earth

Application Park in Baotou, which focuses on magnetic resonance imaging (MRI) technologies, utilising several tons of rare earth permanent magnets in each end product. Compared to superconducting MRI machines, the rare earth MRI system is more efficient in terms of energy saving and daily maintenance, and it does not cause any radiation to human body, according to the chief scientist of the Company XB. However, it is a challenge to lobby local hospitals and governments, obtaining medical permits before manufacturing and marketing. Thus the XB mobilises institutional resources from governmental agencies, in order to achieve better economic performance. Governments play an influential role in this interdependence.

Proposition 2: Interdependent activities with high degree of interactivity but simple ecology features are prone to be symbiotic interdependence. Cooperative projects are more likely to occur, and complementary resources are exchanged more efficiently in this context.

In the case of Fujian rare earth alliance, three leading firms initiate international collaborative projects and cross-country research cooperation. They seek technology integration through overall processes and comprehensive development. Meanwhile, corporate alliances lead proactive interaction with local governments, influencing policymaking processes and co-evolving with local development. Products of the alliance are diversified into interdependent niches, ranging from interior air clarifier, hydrogen storage materials, electric vehicle batteries, structural ceramics, catalysts, and optical materials, etc. Highly symbiotic and complementary assets of these three firms enable efficient decision making and effective cooperation. The alliance has entered emerging markets as leverager, such as electric vehicles and off-shore wind turbines.

Proposition 3: Interdependent activities with low degree of interactivity and complex ecology features are prone to be competitive interdependence. "Co-opetition" – conflict and cooperation exist at the same time. Consequences of this interdependence can go either way – conflicts and ineffective cooperation are more likely to occur in this context.

Both conflict and cooperation can be incorporated into inter-organizational interdependence. Through "coopetition", the exchange of resources is the key issue for understanding relations among organizations. For the recent two years, six rare earth conglomerates have conflicts and cooperation through different interdependent projects. For example, the six leading companies have formed co-pricing mechanisms. They don't really think following the classic "input-output" way, but having joint programs to influence the market as a whole. Although its objective is to cooperate on collective pricing, the result turned out to be low frequency of interaction and unsuccessful cooperation.

Proposition 4: Interdependent activities with low degree of interactivity and simple ecology features are prone to be exploitative interdependence. Cooperative projects and innovations are limited in this context.

Decision-making is constrained by this status of interdependence. The business ecosystem has few species to support versatile innovative interactivity. In some cases, governments have strict regulations on certain application areas, which constrains co-projects to be conducted.

Conclusion and future research

A conceptual framework has been developed to delineate the dynamics of the interdependence. It reveals inter-organisational changing patterns and co-evolving processes within a business ecosystem. High degree of interdependence does not necessarily lead to a healthier ecosystem and high value creation. In contrast, loosely connected interdependence tends to create more sustainable joint programs, and is more likely to benefit from the exchange of resources through cooperation.

This research is only conducted in the rare earths industry which may affect the generalizability beyond this sector. However, it enriches business ecosystem theory, particularly in the aspect of cross-level interactions and interdependence dynamics among different ecosystem players. The findings not only expand the empirical studies of business ecosystems from mainly digital industries to broader areas, but also help to achieve resources' value potentials, integrating industrial dynamics and interdependence theories into business ecosystems.

Future work will involve inter-relationships among suppliers, consumers, policy makers, industry associations, and other related organisations. We will do cross-industry case studies, breaking down the dynamic processes between resource and value, while analysing co-evolution mechanisms of different players in the business ecosystem. As rare earths are critical and strategic resources for both China and the world, this research could also offer implications for both policymakers and social organisations, intertwining co-evolving networks while nurturing shared value for socio-economic and environmental sustainability.

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ORGANISATIONAL ENABLERS OF INTERNATIONAL R&D NETWORKS

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Abstract Cross-case analysis on 6 MNCs' international R&D networks reveals three important organisational enablers of international R&D networks (IRDNs), namely diversity and mobility of knowledge, pluralities of organisational supports and ambidexterity in R&D decision-making, across both emerging and developed MNCs. Each enabler presents a unique dimension to support the operation of international R&D networks. Incorporating with the configuration of international R&D networks in previous literature, we illustrate and explain how these organisational enablers are related to the configuration of international R&D networks. The finding complements existing theories on configurational analysis of international R&D networks and informs the importance of administrative, organisational and managerial factors in understanding and configuring international R&D networks, which has been long neglected in configurational analysis.

Key Words organisational enablers, international R&D network, knowledge mobility, ambidexterity in global R&D

1 Introduction

The 1990s witnessed the fast growth of internationalisation of R&D because of the MNCs' implementation of global R&D strategies (Yoichi, 1991). MNCs from various industries had been internationalising their R&D activities, not only those headquartered in developed countries (Ambos, 2005; Hakanson, 1990) but also, increasingly, those newly established MNCs from emerging countries (Di Minin et al., 2012). Globalised R&D units were becoming active contributors to the global strategy and innovation of MNCs. Strategic management of these globally distributed but internally connected R&D units owned by MNCs, the IRDNs, became a significant problem for both practitioners and researchers.

Earlier scholars identified different roles of R&D units within MNCs (e.g. Ghoshal, 1986; Hewitt, 1980). Then, a configurational approach has been adopted to understanding the networks of R&D units within MNCs (e.g. Ghoshal, 1986; Kuemmerle, 1997), which considered global R&D management is to manage a portfolio of differentiated R&D units that can be loosely connected and referred to as IRDNs. The network based research gained popularity in R&D internationalisation research. However, with the concept of open innovation being proposed, the academic community moved to understand inter-organisational R&D networks to leverage external resources that are critical and complementary for global innovation performance of MNCs. In the recent ten years, there is rather inadequate research on intra-firm R&D network (Liang & Shi, 2013).

While few studies draw attention to the intra-firm IRDNs, practitioner began to expand their global R&D activities again. Many MNCs have established new R&D centres in countries that are beyond their previous focuses whereas others re-designed their IRDNs in terms of organisational structure, functionality and innovation strategy. For example, ABB established their R&D centre in Shanghai in 2006 and IBM set up new R&D centres in Shanghai in 2008, the Oceania (Melbourne) and South America (Rio de Janeiro and Sao Paulo) in 2010. Huawei, a MNC from China, also built three R&D centres in Italy, UK and US in 2011. These new industry practices in R&D internationalisation are not well explained by earlier theories, which necessitates a re-visit to the dynamic issue on intra- firm R&D network.

The literature on intra-firm R&D networks is still sparse but classic, similar to the situation that Nobel and Birkinshaw (1998) noted. These studies focus on configurational analysis on the structures of IRDNs (e.g. Chiesa, 2000; Granstrand, 1978; Hakanson & Nobel, 1993; Ronstadt, 1984), through which researchers were seeking a 'best' structure to organise global R&D. However, they also pointed out that different IRDNs are suitable for different contexts and business strategies, and MNCs with different strategies adopted distinctive approaches to structuring their IRDNs (Miller, 1994; von Zedtwitz & Gassmann, 2002). Its IRDN structure is critical to an MNC's innovation and business because different structures can support different capabilities (Ghoshal & Bartlett, 1988) and different approaches to entering markets (Miller, 1994). Accordingly, this research concentrates on exploring how MNCs have designed their intra-firm IRDNs in the recent years. The analysis builds upon the theoretical streams of R&D units and IRDN classifications (e.g. Birkinshaw, 2002; Chiesa, 1996, 2000; Nobel & Birkinshaw, 1998; Reger, 1999; von Zedtwitz & Gassmann, 2002).

This paper is structured as follows. We begin with reviewing related literature on R&D networks to clarify the essence of R&D network design. Following this, there is a detailed introduction and justification of the methodology on how we select case companies, collect data from them and analyse the collected data. Further, we summarise new insights of intra-firm R&D network in terms of network specialisation, structure and operating mechanism. Finally, we conclude the theoretical contributions and limitations of this research as well as the potential directions for further research.

2 Theoretical Underpinning

2.1 Upgrading of Global R&D Units

Several researchers (Ghoshal, 1986; Mansfield et al., 1979; Ronstadt, 1977) have observed the functionalities of MNCs' overseas R&D facilities. These observations focused on the changing nature of the facilities' roles and responsibilities, which served as theoretical foundations for IRDNs (Howells, 1990). Table 1 summarises some studies on classifying R&D units. The classification of MNCs' overseas R&D units depends on the different capabilities and market coverage of these units. Activities in R&D units include scanning, adapting, developing and researching, depending on their capabilities. The marketing coverage of R&D units can be local, regional, international or global, also depending on their capabilities. Therefore, geographic coverage and R&D capabilities are two main dimensions for differentiating R&D units. These two dimensions are consistent, as, typically, units with higher levels of R&D capabilities can serve a larger scope geographically. Most previous studies, as shown in the table, were highly consistent in classifying R&D units, which suggests the heterogeneity of these units. For instance, Nobel and Birkinshaw (1998) shared Pearce's (1989) definition on three types of R&D units and found equivalences to other classifications.

Table 1 Previous research on classifying R&D units

Studies	**Classifications of R&D Units**			
Ronstadt, 1977	Technology transfer unit	Indigenous technology units	Global technology units	Corporate technology units
Mansfield et al. , 1979	Technology transfer unit		Headquarter R&D	
Hewitt, 1980	Adaptive unit	Local market-oriented unit	Global units	
Pearce, 1989	Support laboratory	Locally integrated laboratory	Internationally interdependent laboratory	
Gupta & Govindarajan, 1991	Implementer	Local innovator	Integrated player	Global innovator
Håkanson & Nobel, 1993	Technical support unit	Adaptive unit	Generic unit	Research unit
Reddy & Sigurdson, 1994	Regional technology units		Headquarter R&D	
Nobel & Birkinshaw, 1998	Local adaptor	International adapter	Global creator	
Chiesa, 2000	Support/Adaptive unit	Local development lab	(Local or global) research lab	Technology scanning units

Source: adapted from Nobel & Birkinshaw (1998, p. 481)

Additionally, R&D units have different processes to upgrade their innovation capabilities (e.g. Hakanson, 1990). The upgrading process can significantly impact the units' heterogeneity, as all the researchers mentioned in Table 2-3 above noted. However, during their observations, only part, not all, of the R&D units in the R&D network upgraded. The increasing heterogeneity of functionalities of R&D units indicates that it is critical to differentiate R&D

units considering their responsibilities and capabilities (Ghoshal, 1986). This is mainly because R&D units in different regions can have different location-based advantages and resources (Bartlett & Ghoshal, 1989) that are critical to particular type(s) of R&D activities. For instance, the R&D unit of an MNC located in a developed country may focus on research-based work whereas the R&D unit of an emerging MNC located in a developed country is more likely to be a technology scanning centre. With this differentiated approach, MNCs can further exploit these advantages and resources to improve the global innovation performance.

These specialisation trends of R&D units (Gerybadze & Reger, 1999; Gupta & Govindarajan, 1991) indicate that global innovation usually involves coordination of these differentiated R&D units to complete global innovation tasks (Granstrand & Fernlund, 1978; Reger, 1999). Traditional coordination of global R&D units relies on formal mechanisms such as policies, liaison person and committees (Reger, 1999). Centralisation and autonomy have been two focuses in the formal mechanisms of coordinating global R&D (Chen et al., 2012; Dobrajska et al., 2015). While centralisation can improve efficiency for technological and fundamental innovation, decentralisation can be beneficial to effective market response. Similarly, autonomy can encourage researchers to focus on future technologies whereas mandate can tighten the linkage between R&D and business.

From an information processing perspective, Egelhoff (1982) argued that coordination is the key to linking structure to strategy. R&D units' methods of coordination and communication became significant to form and support an efficient and effective R&D network. Proper choice and use of coordination mechanisms have a significant impact on the overall performance of an MNC's global R&D (Doz & Prahalad, 1984). Reger (1999) further specified selection of different types of communication mechanism was based on organisational factors and geographic factors. The diversity of geographic locations makes the coordination of specialised R&D units more complex. Many other factors, such as level of cultural differences, should also be considered.

Other issues can also be influential in coordination, as identified in the literature. For instance, every R&D unit is set in different strategic contexts that require different strategies for control and coordination (Gupta & Govindarajan, 1991). The context of an R&D unit is, however, a location-based issue, which can be very complicated to discuss. Global R&D requires frequent and substantial knowledge flows to coordinate (Kim et al., 2003), which relies largely on information systems that improve the effectiveness and efficiency of coordination more than the formal mechanisms (Kim et al., 2003). Adoption of information systems has changed the pattern of coordination in global R&D (Moitra, 2008). There has been a trend for informal mechanisms to complement or replace formal mechanisms over time (Martinez & Jarillo, 1989).

2.2 International R&D Network- Configurational Classifications

Most previous researchers decomposed global R&D structure as a network of R&D units that are dispersed geographically with different innovation capabilities and location advantages. A network of global R&D is a connected system coordinated with differentiated and dispersed R&D units. Within the network, there are many flows of knowledge, information and/or people through global R&D projects. Researchers often analysed the structures of these networks to propose classification systems for global R&D (e.g. Birkinshaw, 2002). Reviewing all these studies across different industries will provide a comprehensive understanding of IRDNs.

Table 2 summarises six studies that classify global R&D structures. Most researchers (e.g. Birkinshaw, 2002; Chiesa, 1996; von Zedtwitz & Gassmann, 2002) have concluded that a firm's IRDN may ultimately evolve to be a global integrated network (GIN). However, definitions of GINs vary. Chiesa (2000) defined two different GINs. One follows a network structure that consists of dispersed R&D units in the same product/process/technology area, whereas the other is a specialised contributors structure in which each unit specialises in a few disciplines and a piece of R&D work and is managed by a coordinator R&D centre. Gassmann and Von Zedtwitz (1999) argued that a GIN is a structure in which "central R&D evolves into a competency center among many interdependent R&D units which are closely interconnected by means of flexible and diverse coordination mechanisms" (Gassmann & von Zedtwitz, 1999, p. 243). They further elaborated this concept, stating that networks "have distributed research as well as development worldwide and aimed for global coordination of R&D activities" (von Zedtwitz & Gassmann, 2002, p. 579). This definition is very similar to Birkinshaw's (2002). The differences in definitions of GINs relate to the different dimensions used to classify IRDNs. Chiesa's (2000) classifications emphasised the specialisation of R&D capabilities, while others (e.g. von Zedtwitz & Gassmann, 2002) argued that, in GINs, R&D units become less heterogeneous in their capabilities, and all serve as global contributors.

Table 2 Previous studies on intra-firm R&D networks

Studies	**Classifications of IRDNs**	**Industry**	**Dimension(s)**
Miller, 1994	-Corporate home-based -Regional generalists -Partly dispersed -Dispersed	Automobile	Geographic Dispersion
Chiesea, 1996	*Isolated specialisation *Specialised contributor *Integrated based	Technology intensive	Coordination
Gassmann & von Zedtwitz, 1999	-Ethnocentric centralised -Geocentric centralised -R&D hub -Polycentric centralised -Integrated	Multiple	Dispersion and coordination
Birkinshaw, 2002	*Integrated *Loosely-coupled	Multiple	Observability and mobility of knowledge
Chiesea, 2002	-Centre of excellence -Supported specialised -Specialised contributor -Integrated	Technology intensive	Coordination and capability of R&D units
Von Zedtwitz & Gassmann, 2002	*National treasure R&D *Market driven *Technology driven *Global	Multiple	Dispersion and Specialisation of R&D

Most studies show consistency in the variance among IRDNs. Most of these studies follow a four-type classification while one of them is home-based R&D, in which most R&D activities are conducted only in the headquarters although the company serves global markets. Such a headquarters-centred R&D structure may not be a very good example of an IRDN whose definition focuses on global dispersion and coordination of R&D units. The other three types present global IRDN structures. The first type is a development-oriented IRDN, where development units are dispersed worldwide, and research units are relatively central to the home base. The second one is similar to the first one, in which the research units are globally dispersed rather than development units. The last type is a structure in which all development units and research units are globally distributed. The R&D activities of the last structure require global specialisation and coordination.

2.3 Summary: Research Gap

According to these studies, well-established MNCs are now operating the same type of IRDNs, i.e. GINs, in which R&D units all become centres of excellence in one or a few technology domains or product categories. This contrasts with earlier classifications (e.g. Chiesa, 1996, 2000) that suggest an IRDN has only a few centres of excellence that are responsible for supervising other units. These IRDNs, despite being of the same type, show differences in global R&D operations and performances. Such a theoretical gap indicates there should be additional factors that influence global R&D management and shapes IRDNs. These factors have been uncovered in previous studies, so they cannot explain contemporary IRDNs. Thus, new research is need to revisit the topic to explore and clarify these factors.

Meanwhile, the research on R&D units and previous studies on intra-firm R&D networks has laid a solid foundation for further exploration. Particularly, these studies enabled elaboration of the definition of the IRDN, that is, specialised R&D units in the home and overseas markets established by a MNC, connected by tight or loose controls, complex or simple flows of people, information, materials and technologies with appropriate communication mechanism (adapted from Birkinshaw, 2002; Chiesa, 2000; von Zedtwitz & Gassmann, 2002). Meanwhile, the review suggests the intra-firm R&D network is currently the research gap. Over ten years ago, this topic had been studied, especially the concept and structures of IRDNs. However, the industrial reality has changed dramatically compared with the situation ten years ago. Moreover, the operating mechanism of IRDNs has not been systematically studied. Thus, this topic is worth revisiting. In order to capture the new phenomenon (Yin, 1994), case study can be selected as the main research method, as it is common in previous studies.

3 Research Methods- Case Study Design

The variances in IRDNs in previous literature and current practices suggest the necessity for a multiple and inductive case design (Eisenhardt, 1989) so that the researcher can capture the variances and build up a better theory to describe and explain them. Similar to a general qualitative research design proposed by Richards and Morse (2007), Yin (1981) and Eisenhardt (1989) developed two consistent processes for theory development through case studies. Their processes will be synthesised for implementation during the case study on IRDNs.

3.1 Unit of Analysis

To be linked with previous literature (Table 2), this research will choose a unit of analysis similar to that used in extant studies. Many MNCs have experienced changes in their IRDNs in recent years; however, previous studies have not captured these recent changes, instead only providing snapshots of the intra-firm R&D network. Hence, the proper unit of analysis for this research is the IRDNs of MNCs including their geographic, operational and strategic developments in the past.

3.2 Selection of Cases

In order to study IRDNs, suitable case companies will be chosen through the theoretical sampling method that likely allows the development of more plausibly reliable theories from variances or even extreme IRDN cases (Eisenhardt, 1989; Siggelkow, 2007). To be specific, the potential cases should include both established MNCs from developed countries, which have been studied in previous research, and emerging MNCs from developing countries, which have not been covered previously. Of course, these MNCs should have established IRDNs.

R&D management theory suggests that it is important to understand R&D within its industrial and national context. There are four industries that have frequently been studied previously (Liang & Shi, 2014), i.e. hi-tech industry, automobile industry, machinery industry and FMCG industry. These four industries can be very proper settings for IRDNs due to their R&D intensity, R&D FDI intensity and variances in industrial dynamics that allow understanding of how IRDNs interact with environmental changes (Ethiraj & Levinthal, 2004). Meanwhile, Liang and Shi (2013) argued that European MNCs and Chinese MNCs are currently very popular for research because of their active roles in R&D internationalisation. For comparison reasons, it is more favourable to have paired cases from both regions in the same industry.

To consistent with previous research (Table 2), this research will take a replication strategy to select cases. The initial case candidates will be selected from cases in the previous research but with respect to the recent industry developments in IRDNs to offer novel stories for theory building. Therefore, this research will focus on cases that have changed their IRDN operations after 2002[1] when many established MNCs set up new R&D centres in China.

With all these criteria, six companies were chosen for conducting case studies. These cases can be compiled into a matrix (Figure 1 below), which allows exploration of the diversities of IRDNs in rich contexts.

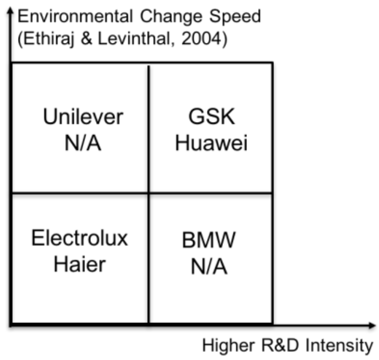

Figure 1 Summary of case selection

3.3 Data Collection

Before data collection, secondary data, including Chinese news from Xinhua Agent's multimedia database and English news from LexisNexis, official websites of case companies, relevant industry reports, public reports on global R&D of MNCs, company annual reports and relevant books on these case companies' global innovation, were searched for background research. For both Chinese companies, the background search focused on their history as much as possible, whereas for those established MNCs, the background search mainly focused on data after 2002.

After the background research, fieldwork was conducted. Before the fieldwork, however, it is essential to have a data collection protocol in order to consistently collect data for multiple cases (Yin, 1994) and to ensure the reliability of this research (Gioia et al., 2013). A generic case study protocol for data collection was developed to include all detailed research questions

[1] Previous literature on intra-firm R&D networks ends in 2002, as seen in Table 2.

on IRDNs including IRDN's R&D process, R&D context, internationalisation path, IRDN configurations and reconfigurations.

Data have been collected from 2013 to 2015, with at least one on-site visit to each case company. Primary data were mainly collected through semi-structured interviews, complemented with observations and archival data. Theoretical saturation of data has been considered in data collection. Cross-case comparison has been conducted to examine whether extra data collected will bring out new insights into IRDNs. In total, there are over 70 valued semi-structured interviews, 167 pages of selected transcription, 73 pages of fieldwork notes, over 200 pages of archival data, and over thousands of news articles related to the topic as well as over 11,444 pages of annual reports.

3.4 Data Analysis

An inductive grounded approach (Glaser & Strauss, 1967; Miles & Huberman, 1994; O'Reilly et al., 2012) was adopted to analyse all transcriptions, fieldwork notes and secondary data on (static) configurations and capabilities of contemporary IRDNs. Three-phase coding was conducted, as Table 4 below.

Followed Glaser and Strauss (1967) approach to primary coding, the first coding phase was to generate open codes from keywords extracted from original conversations in the transcriptions and related secondary data. This resulted in initial primary coding systems generated with these integrated open codes from each case. Typically, each case has around 15 to 25 open codes from primary data. The second coding phase was axial coding, in which primary codes were linked and clustered to identify categories, similar to Gioia et al. (2013) first-order constructs. Before axial coding, the open codes for each case were synthesised and consolidated at the cross-case level and resulting in 18 consolidated primary codes. These codes were categorised into 3 axial codes, which enables to seek initial cross-case patterns to understand IRDNs. The final round was selective coding, linking these axial codes to a theoretical theme (Table 4), similar to Gioia et al. (2013) second-order constructs, that is, organisational enablers of IRDNs.

4 Findings

4.1 Case Profiles

Table 3 below presents an overview of global R&D of these case companies, which indicates different contexts of IRDNs. In this chapter, cases will be reported individually with the profile and contexts of the case companies and the current features and historical development of the IRDNs. Current IRDNs of these case companies are all GINs but with many variances in their contexts, operations and development processes. The variances of these IRDNs are related to whether the MNC is emerging or established and indicate potential patterns across cases and enables cross-case synthesis to understand configurational features and organisational enablers.

Table 3 Summary of global R&D of case companies

	BMW	Electrolux	GSK	Haier	Huawei	Unilever
Year founded	1916	1919	2001, dating back to 1715	1984	1987	1929, dating back to the 1880s
R&D spending (in million)	€ 5,169	SEK 3,210	£3,560	￥2,399	￥59,607	€ 1,005
R&D intensity*	5.61%	2.60%	14.88%	2.70%	15.09%	1.89%
Industry average**	4.50%	2.10%	13.00%	1.70%	3.95%	1.30%
Number of countries covering	Over 150	Over 150	Over 150	Over 150	Over 150	Over 190
Overseas market size***	87.3%	96.4%	73.0%	50%	57.54%	58.0%

* R&D intensity is the percent of R&D spending in annual revenue.

** Industry average is from PwC Stategy & (2016).

*** Overseas markets size is measured as the percent of overseas sales volumes in total sales volumes in 2015.

Source: summarised from annual reports of these companies

4.2 Cross-case analysis

The cross-case analysis also reveals three organisational enablers of IRDNs, as shown in Table 4 below. The illustrative quotations can be seen from the appendix and are marked accordingly. Specifically, diversity and mobility of knowledge indicate operational enablers as the content in IRDNs. Pluralities of organisational supports refers to structural enablers in IRDNs, and the last theme explains managerial enablers in IRDNs. Collective, they explain what enables MNCs to operate their IRDNs efficiently.

Diversity and Mobility of Knowledge. As IRDNs are multinational, the operation of such networks can benefit from diversifying and mobilising knowledge. In terms of the multinationality nature, IRDNs enable MNCs to diversify their technology knowledge bases, as shown by all cases decentralising and specialising research centres to various locations worldwide to develop different technologies. Meanwhile, as mentioned earlier, location decisions for these R&D facilities are carefully considered to access local clusters with heterogeneous focuses on and advantages in innovations, as shown in BMW, GSK and Huawei's case. This indicates that, operationally, IRDNs are designed for diversifying the MNCs' technology base. Further, for diverse markets, IRDNs also need to respond to heterogeneous local requirements for innovations. These requirements include customer needs, local institutional requirements and local conditions, which are local knowledge for MNCs. In this sense, IRDNs also need to process diversified market knowledge.

The diversified market and technology knowledge require intensive coordination internally to enable economies of scope to be achieved. Thus, knowledge mobility also serves as an enabler for IRDNs, particularly when R&D facilities are specialised. All the case companies have adopted Intranet-based information systems for knowledge management, including depositing documentations and archives, sharing personal experiences, technology and knowledge, and connecting people for collaborative work and learning. For instance, Huawei's W3 Portal is an integrated system for sharing personal experience and official archives, Electrolux has two databases to share detailed modules information across regions, GSK has developed the Knowledge Management Toolbox, and Haier has an online platform with applications to facilitate coordination at distance.

Table 4 Evidence and primary coding for IRDN organisational enablers

Illustrative Quotations	Primary Codes	Axial Codes
Electrolux (Q7), Haier (Q3), Huawei (Q14), Unilever (Q6-Q8)	2.1.1 Heterogeneous local requirements for innovation	2.1 Diversity and Mobility of Knowledge
BMW (Q4-Q5, Q12), GSK (Q4), Electrolux (Q4), Haier (Q4), Huawei (Q5, Q11), Unilever (Q5, Q6)	2.1.2 Diverse technological knowledge bases	
BMW (Q11), GSK (Q4), Huawei (Q5, Q6), Unilever (Q4, Q14)	2.1.3 Heterogeneous local clusters for innovation	
Electrolux's architecture leader (Q15), Haier (Q10), Huawei (Q6), Unilever (Q8)	2.1.4 Strategic planning for knowledge integration	
BMW (Q10-Q12), Electrolux (Q10, Q16), GSK (Q3), Haier (Q10-Q11), Huawei (Q12), Unilever (Q8, Q11)	2.1.5 Facilitate internal knowledge sharing	
All cases	2.1.6 Information system for internal knowledge management	
GSK (Q11), Huawei (Q11)	2.2.1 Matrix organisation	2.2 Pluralities of Organisational Supports
BMW (Q4), Electrolux (Q14), GSK (Q4), Haier (Q5), Huawei (Q9), Unilever (Q4)	2.2.2 Cross-functional and interdisciplinary teams	
BMW (Q9), GSK (Q3), Unilever (Q5, Q8)	2.2.3 Internal competition in R&D	
All cases, particularly GSK (Q16), Haier (Q14), Huawei (Q9), Unilever (Q8)	2.2.4 Standardised R&D process	
BMW (Q8), Electrolux (Q14-Q15), GSK (Q4), Haier (Q11), Huawei (Q10), Unilever (Q8, Q9)	2.2.5 Organisational interfaces with other departments	
BMW (Q7), GSK (Q4), Haier (Q9)	2.2.6 Direct linkage with top management	
Haier (Q11), Huawei (Q12)	2.2.7 Supportive HR policy	
GSK (Q5), Haier (Q8), Huawei (Q8)	2.2.8 Platform to leverage external resources	
GSK (Q15), Huawei (Q16, Q18)	2.2.9 Innovative culture	
See "Globally dispersed and specialised research centres", "Globally dispersed and specialised development centres" and "Strategic planning for knowledge integration"	2.3.1 Centralised vs. Decentralised R&D Planning	2.3 Ambidexterity in R&D Decision-making
See "Decentralised R&D workflow-research, development and localisation" and "Facilitate internal knowledge sharing"	2.3.2 R&D Autonomy vs. R&D Mandate	
See "Diverse technological knowledge bases" and "Open innovation and collaboration"	2.3.3 Open vs. Closed Innovation	

Besides information systems, there are also several other means by which to facilitate internal knowledge sharing within an IRDN. For instance, Electrolux and Unilever's dispersed GDCs usually coordinate several product lines for developing new products with shared modules/components. GSK usually organises interdisciplinary discussions over diseases. Haier promotes personal rotation in business units and R&D centres for sharing knowledge. Huawei and BMW emphasise R&D staff training and educating for knowledge sharing and accumulation. More formally, several companies take advantage of strategic planning (Haier, GSK and Unilever) and regional planning (Huawei) to enhance knowledge integration among specialised R&D facilities, as each facility will be clearer on its position in the IRDN and focus on R&D activities.

Pluralities of Organisational Supports. Organising globally distributed R&D facilities for an R&D project is far more complicated than having one centralised facility. With a distributed structure, IRDNs require organisational supports for their global operations. Plural levels of organisational supports have been identified for effective IRDN operations, namely, group level, department level and organisational level. These pluralities of organisational supports suggest the complexity of IRDN operations and the need for a systematic approach to supporting these operations.

Firstly, all the cases suggest that interdisciplinary teams can be essential for global R&D, although the uses of such teams differ across R&D workflow. For instance, GSK, Electrolux and Unilever's research teams are interdisciplinary whereas BMW, Haier and Huawei's development teams are interdisciplinary. Meanwhile, a matrix organisation has also been commonly used for global R&D teams, as suggested by GSK, Huawei and Unilever's cases, in that a dual structure of project-based teams and hierarchical departments has been applied to all their R&D teams. Meanwhile, some case companies have introduced internal competition for global R&D, which can be another instrument to support efficient IRDN operations, as found in BMW, GSK and Unilever. Meanwhile, standardisation of R&D workflows has become a general enabler for all the case companies as a remedy for the geographical decomposition of R&D workflows. Thus, standardising workflow is an important enabler for R&D workflow interdependence. Standardised workflows can ensure the quality and mutual understanding of deliverables for the next sequential activities that will likely be conducted in another country and by another group of people. Coordination and communication cost can be reduced with these standardised workflows. Specifically, there are several different ways to standardise the workflow. Emerging MNCs tend to hire a consulting firm to help them standardise their R&D process, as Haier and Huawei did. Firms that grew up from M&As tend to focus on their traditions in the R&D process and promote these efficient processes to accommodate different R&D habits from the acquired companies, as shown by GSK, Unilever and Electrolux.

Organisational supports at the group level mainly facilitate the operations within an R&D project in an IRDN. IRDNs also interact frequently with other functional departments, such as marketing and manufacturing. Thus, IRDNs also require support at the cross-functional department level. Specially, all cases show a pattern to standardise organisational interfaces between R&D department and other departments, either across the consolidated and collaborative R&D process (BMW, Electrolux, Huawei and Haier) or from decision-making in R&D projects (BMW, GSK and Unilever). IRDNs can also be directly linked to top management, as BMW's top management directly leads the Design Studios and GSK's Discovery Investment Board directly manages the DPUs. Besides, Haier and Huawei have transformed their HR policies to improve the performance measure and incentives of R&D staff for IRDN operations.

Organisational supports at the department level facilitate IRDN operations across functional units. There is also evidence that effective IRDN operations require support at the whole organisation level. Innovation culture can be an important instrument for IRDNs, as found in GSK and Huawei's cases, where innovation culture, particularly the norm of cooperation, is an enabler to improve the performance of global R&D projects with distributed R&D facilities. Meanwhile, the implementation of open innovation with IRDNs also requires organisational level support. Several cases companies, such as GSK, Haier and Huawei, have established different platforms that support the leverage of external resources into their IRDNs. The establishment of these platforms indicates that organisational support for IRDNs should be considered broadly to facilitate the deployment of internal resources and leverage external resources together for global innovation.

Ambidexterity in R&D Decision-making. Another organisational enabler of IRDNs is about the R&D decision. Traditional R&D decision-making is centralised for R&D managers, who decide to explore future technologies or exploit existing technologies. The IRDNs are decentralised and multinational structures; in deciding how best to operate them, MNCs need to consider extra factors such as, trade-off between efficiency, responsiveness, innovativeness and cost in a global context. Thus, there has been an ongoing academic debate on centralisation and decentralisation of global R&D decision for many years (e.g. Govindarajan, 1986; Siggelkow & Levinthal, 2003). The cases in this research suggest a mixture of both sides, as all the cases illustrate a pattern of ambidexterity in centralisation and decentralisation of R&D planning. As for multinationality, BMW and GSK's top management engage in R&D decisions, which is a more centralised approach, whereas BMW's research decisions are decentralised to each facility and GSK's development decisions are also more decentralised. As for R&D workflow interdependence, Electrolux's GDCs are specialised in product categories. Within such categories, the R&D decisions are centralised in that GDC; in contrast, while considering the whole IRDNs, the development decisions in Electrolux are decentralised to each GDC. In this sense, ambidexterity in centralisation and decentralisation enables Electrolux to benefit from its multinationality for efficient IRDN operations. These cases indicate, in the global context, that IRDNs, by balancing centralisation and decentralisation in R&D decisions, can take advantage of the multinationality and R&D workflow interdependence to improve the performance of global innovation.

Another ambidexterity in IRDN is R&D mandate versus autonomy, which reflects the trade-off between business needs and technological feasibility. Mandates from headquarters' R&D department, requested by the marketing department, indicate the urgency that R&D projects respond to potential market needs by exploiting owned technologies. However, scientists and engineers always prefer an autonomous status in their R&D activities, as they can explore whatever they want to satisfy their curiosity about science and technology, which likely improves their output. In IRDNs, R&D mandate and autonomy can take advantage of R&D resource interdependence for better performance. For instance, Huawei's overseas research centres are autonomous from regional subsidiaries and conduct research freely on different technology domains. However, they are also under mandates from regional R&D headquarters and the central R&D department through technology roadmapping to integrate with corporate strategy. Huawei benefits from ambidexterity in R&D mandate and autonomy to improve its IRDN's efficiency and relevance for the business. Another example is found in Haier, which makes use of ambidexterity in its R&D mandate and autonomy for balancing local responsiveness and global efficiency. Haier's each centre is responsible for each region, which is an autonomous and responsive method. Haier also conducts strategic planning for technology development together with all centres for R&D coordination, which is an R&D mandate and an efficient approach.

Further, R&D resource interdependence involves open innovation. IRDNs serve as important tools for MNCs to implement open innovation, for its multinationality and location advantages. Thus, the last ambidexterity for R&D decision-making is open innovation versus closed innovation. MNCs need to trade-off what can be open and what needs to be closed in global innovation with the IRDNs. GSK has been very open in its medical and biotech research but remains closed in the development and testing stages. Unilever has followed a similar pattern in open innovation. Such ambidexterity indicates how MNCs would like to have a balance in IRDNs to protect their technology cores while wishing to open up and leverage external resources for global innovation. The only exception is Haier, which has been increasingly opening up the whole company with its HOPE.

5 Discussion and Conclusion

Previous research on intra-firm R&D networks focused largely on descriptions and summaries of the current situations of industrial practices (Chiesa, 2000; Granstrand, 1999; Hakanson & Nobel, 1993; Ronstadt, 1977). The narrative nature of these studies prevents them from embedding management theories to understand global R&D management. Consequently, these studies were taxonomies that could describe these IRDNs but were inefficient to explain and predict the on-going development of MNCs' global R&D activities.

In contrast, this research develops deepen the understanding of IRDNs with organisation theory and aims to explain the organising nature of IRDNs. Beyond the configurational analysis, this research focus on explaining contemporary IRDNs with the organisational enablers that facilitate the global operations of specific IRDN structures. In this sense, the research can be seen as an alternative approach to understanding IRDNs. The new constructs of organisational enablers are empirically derived from grounded data. Distinct from previous studies, these constructs are theoretically developed rather than classifications of all cases. Therefore, it provides new insight into global R&D management by identifying the "infrastructure" of IRDNs using related theories from strategic management and organisation theory.

This finding provides two major insights into understanding IRDNs. First, traditional studies in the field do not explicitly explain the underlying mechanisms of IRDNs nor the linkages between IRDNs and business strategy. However, it has been evident from both management theory and practices that R&D should be linked to firms' business strategies (Gregory, 1995; Moser & Plante, 1987; Roussel et al., 1991). This linkage was also highlighted in one of the traditions in R&D internationalisation research – how firms can obtain strategic advantages from international expansion of R&D (Liang & Shi, 2015). However, the mainstream research in this area focused on understanding location advantages and global R&D strategy while neglecting the way in which R&D supported business strategy in the global context. Drawing on R&D management and strategic management, this research advocates the importance of organisational enablers of R&D to understand this linkage between global R&D structure and strategy. Actually, the organisational enablers are more "invisible" side of IRDNs, comparing to the structure of IRDNs that can be seen from the geographic dispersions of the IRDNs and can be easily imitated by rivals when they establish new R&D centres in the same locations. However, organisational enablers are hidden factors behind the structures and locations of IRDNs and they serve as the "secret" that determines how a specific structure operates and contributes to the business strategy. Therefore, this research enriches the connotation of IRDN by empirically proposing the organisational enablers of R&D. These contributions deepen the understanding of the interactions between global R&D management and global strategy.

Second, previous theory on intra-firm R&D networks (e.g. Miller, 1994; Chiesa, 1996; Gassmann & von Zedtwitz, 1999; Chiesa, 2000; Birkinshaw, 2002; Von Zedtwitz & Gassmann, 2002) has mainly focused on structural classification of networks and neglected the underlying logic of organising, except for Birkinshaw (2002), who considered the importance of knowledge and communication in shaping the structures of IRDNs. These studies took the international business (IB) context of R&D networks for granted, as in their studies, IRDNs meant multinationality of R&D facilities and their focus was on the network structure of these multinational R&D facilities. Their studies explained the different roles of R&D facilities in the networks. This research suggests that the IB context means more than multinationality, as the context provides opportunities and challenges to organise R&D activities. MNCs need to consider organisational enablers affecting the performance of IRDNs in the IB context since IRDNs are more than a sum of all multinational facilities. Therefore, this research is based upon the theory of IRDN structure to understand organising and strategical issues hidden in the structure of IRDNs.

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BMW

"We have several R&D centres around the world. They concentrate on different automobile technologies and locate in advantageous areas… We concentrate and become efficient with our interdisciplinary teams… Definitely, FIZ is the dominant one and others complement FIZ, and we can have a set of advanced technologies [that] enable us to embed with customer needs. We try to balance quality, innovation, flexibility and cost to fascinate customers with these technologies and integrate our vehicles into their life." (Q4)

"…a car involves very complex but differentiated components with various technologies. BMW tries to decompose key components from different technologies. Then, each research centre can focus on different but complementary technologies for driving. Therefore, each centre is specialised into a few of all [the] key components respectively whereas, collectively, they consist of a portfolio of technologies that can support innovations [for] a car as a whole." (Q5)

"Although our research is future oriented, capturing values from our technological advantages relies on innovatively designed new vehicles. Thus, our design process is at the heart of our R&D and directly engaging our top managers. The design team works alongside the whole [development] process and coordinates various departments. We established different studios to design for BMW, Mini and Royce-Rolls respectively, as each brand [is uniquely positioned] in the market… These design studios [are] also located globally." (Q7)

"We have developed a collaborative process for design… The initial phase in designing a model is to negotiate with various departments to clarify the [technological] feasibilities and functionalities and finally find a solution to highlight new technologies [developed internally]… We need to find a balance between these technological features and driving needs." (Q8)

"Our office [BMW Beijing Engineering Centre] localises products for the China markets… mainly through testing and implementing headquarters' [environmental] standard practices… Similar to other [engineering] offices, we also support the development of local products for China, as the market segments and regulations for premium cars are different from other markets… We work closely with headquarters and Chinese factories to make us better serve Chinese markets and meet expectations and unique needs in China." (Q10)

"We regularly assist the R&D department [FIZ] and Car IT centres in Munich to understand consumer information… we also conduct our own research for China and the global markets and we are involved in new model development… Our lab also helps the group to better integrate into the Chinese market. We incorporate information on Chinese characteristics into products and our technological advantages can be used to tap the Chinese market concisely. We also build up linkages with domestic partners. For example, we are collaborating with China Unicom on e-platform with our iDrive system…" (Q11)

"We have an integrated innovation network that covers major technology domains for automobiles. We also need efficiency to meet the diversity of drive needs. We create channels to mobilise the expertise in our technology bases within our network. Then, local needs can be met from distributing our technologies globally.” (Q12)

Electrolux

“Global Technology Centres (GTCs) have developed their own technology competence for different modules. For example, the microprocessor is developed in the North America [GTC] and the switched-mode power supply is developed in Italy. They also interact to cover most technology solution requests.” (Q4)

“Since for some boards, like power boards, we need variants of the board depending on the region, because [of] the voltage, because [of] some stuff we have to add or remove… We can have a global project to develop this board. But not all boards are really the same variant. The board is [overall] the same, but you change, maybe, two components, to have it for North America, and one variant for Asia Pacific… But, all such boards are within one bill of materials, with a full list of components and different combinations of these components to make up different versions of the board, to fit different market requirements.” (Q7)

“We consider [modularisation] as much as possible to develop [a new product]. [For example,] if [the new product] needs a new board with the modules we have already available, and [if] we try also to have this board fitting global requirements, [then, it] is a global solution [for sharing]… There are project managers that are organising these modules to build up the applications. In this way, with modularisation, we are able to have a shared knowledge, shared work, and also have [as much standardisation as possible].” (Q10)

“If we have different R&D, we have also different experience and backgrounds, so everybody wants to develop in different way[s], [for] a project. What we don’t know is duplicate solutions. If we have one solution working well, we want, we must use that solution.” (Q14)

“…The architecture leader is the person aware of what are these capabilities in Electrolux, meaning people, shared skills, and also modules that he can use to build up the appliance, meaning that, as an example, we can build for Thailand, so for Asia Pacific, a refrigerator with a board developed from Brazil R&D, with the chassis built here in Susegana, so designed by our mechanical engineers, and then with the production engineering in Thailand, so other engineers that take care of production workflow… The architecture leader, even if is here [in Susegana], is managing all these activities to have the final product, this, what is now the globalisation in Electrolux.” (Q15)

“Integrated with our consumer insights and know-how of global markets … the new R&D structure helps transfer our technology and experiences from our professional business to the development of new products… Our global modular platforms facilitate the spread of successful launches from one market to another, with adaptations to local requirements. The platforms also support the company’s objective of offering more resource-efficient products to global consumers and decrease the risk and possibility of failure in new product development.” (Q16)

GSK

“R&D underpins all our businesses and is the key to triggering the revenue… We need to regularly break barriers for our innovation and embrace open and flexible ways to innovate for global markets. [Consequently,] our R&D structure is changing due to the changing environment, technology and requirements of businesses." (Q3)

"A DPU means a tiny but interdisciplinary team for research. The smaller size can make us concentrated [in] and passionate [about] sophisticated areas to discover new drugs... Each DPU is a small research centre for specific drugs. We are independent of each other but keep updating and communicating [with each other] to check for potential partnership and coordination... However, we also compete for funding from a board consisting of top managers and external experts. This heavily pushes us to be efficient, outcome-centric and incorporating business needs." (Q4)

"Open innovation and collaboration is also central to advance our research. We have established open labs in Spain and South Africa, for example, to invite external researchers to utilise our facilities, resources and expertise. Some remarkable products, such as the first preclinical candidate to treat visceral leishmaniasis are developed this way… We also have seed fund and support for small biotech companies that focus on niche and alternative treatment. We can access or buy patents developed with our funding for their research, to share our risks in emerging technology." (Q5)

"Our R&D project is truly global…For instance, a newly launched drug may be discovery and developed in the UK, designed [formula] in the US, tested globally, validated for manufacturing in Singapore and, finally, localised and assembled in China." (Q11)

"Innovation is crucial for GSK. As our business grows, we are always cultivating our innovative culture and optimising our R&D operations through restructuring [and] breaking the barriers in R&D practice… so that innovation can be nested in GSK and our innovation performance can be improved in the long term and closely embedded with our business performance…" (Q15)

Haier

"These five global research centres are responsible for research and localisation for each own region … [For research,] the main responsibilities include developing new technology, monitoring frontiers of technology in the industry and support product development… not only for their regional markets but also for other regions… [The] localisation activities include two sides to make us better and faster integrate into local and regional markets. One side is to develop new products for the regional markets when there are consumer needs. The other, dominated [by] them [the two newly established ones], mainly includes adapting and adjusting mature products developed by other centres with local preferences…" (Q3)

"We only formulate technology strategy to consider focal research directions for all research centres, which is a top-down approach to managing global research centres. We measure their performances on closing the gap between the expected capability of an R&D centre and its current one. However, we do not force them to be differentiated and specialised, which seems to be too subjective. Mainly, the differentiation and specialisation of these research centres are natural consequences of the interaction between research centre and the local markets. Each centre mainly focuses on R&D for local demands that may require different technologies. Each centre is adaptively specialised into these domains… Research centres also recruit local talents that vary from [one] region to another… The strengths of each research centre also depend on the people it can recruit.” (Q4)

“We have transformed to the operation team system for new product development. There are many, many operation teams. Each is a cross-functional team and meanwhile an independent firm for a specific type of product, such as air conditioning. They develop their products freely but should [be] responsible for the profit that determines their salary, not the bonus, salary exactly.” (Q5)

“HOPE (Haier Open Platform Ecosystem) is a public online platform that seamlessly integrates market and technology. Haier only takes a role as a mediator to enable such integration. With this platform, we could broaden the breadth and width of resources we leverage, as different players can all participate in the platform…We have several interesting products that are developed via this platform, for example, [an example of how a particular product is developed with this platform]…” (Q8)

“Internal employees participate in the HOPE through proposing [a] solution or conception of products. Their proposals will be reviewed and realised through Haier’s operations if approved by consumers. This helps Haier to encourage everyone, either within or without the company, to become ‘makers’ who can creatively develop new products with their talents and experiences and through the support of Haier’s resources and platforms on commercialisation and production.” (Q9)

“When formulating annual R&D plans and overall R&D strategy, we first draw out the technology roadmap for global R&D, then consider coordination and integration between different R&D centres, through our global discussions and finally discuss strategic roles of each R&D centre together… My department will support coordination between them and develop channels to facilitate their cooperation at project and technology level, such as visits and videoconference on fixed terms. This process is not only determined by ourselves but also involves top management.” (Q10)

“For projects, all centres are open. Everyone with specific skills that are in need of a project will be freely involved in the project, which helps the mobility of knowledge along our R&D network… Collaboration for global R&D is complicated. We also have negotiated with related departments and consider what can be better performance measures and codes of practice for flexible participations, particularly for the short-term participants in long-term projects.” (Q11)

Huawei

“We have established a portfolio of research centres around the world. A global vision is important. The [technological] sources are globally distributed. We have to go to different places to access [them]. In Huawei, each of our centres has its focal domains on technology in relation to several products or a fundamental one, such as wireless technology, fix network, enterprise networking, cloud computing and big data. They are the technological bases to support Huawei's customer-centred strategy… The main responsibilities for research centres are similar, including technological scanning, technology platform development and collaboration with local research facilities, and recruiting talents.” (Q5)

"…the head of each research centre is of the same authority [as] a CEO of a regional subsidiary, which ensures that R&D is planned only with core business requirements and will not be manipulated by local subsidiaries' interests. With autonomy, we [local research centres] can cooperate freely with multiple renowned universities for a broad range of technologies, such as advanced optical transmission systems done here… It also helps to improve the influence and control of the central R&D department at our headquarters, either to facilitate the coordination of global R&D projects or to improve the implementation of strategic R&D planning." (Q6)

"JICs (Joint Innovation Centres) serve an enabler to boost customers' business with our technological expertise. With these JICs, we can easily interact directly with our customers and respond to their business needs at an ever-fast speed… They work like a sensor to transfer customer needs to us. With these insights, we could collaborate specifically with different customers and deepen our relationships with them. Meanwhile, JICs are similar to platforms for collaborative innovations to shape the next generation technology." (Q8)

"IPD (Integrated Product Development) is a standardised process that is achieved through the collaboration of cross-functional teams, consisting of R&D, marketing, production and supply chain staff. Each member has the right to terminate the whole NPD project in the planning stage... [An IPD team] is an independent firm within Huawei and to deliver valued innovation at an accelerated pace." (Q9)

"…[IPD] enabled Huawei to break the centralised R&D decision-making process and establish a decentralised, balanced and efficient one to smooth our global innovation… This transformation reinforces our customer-centric strategy, with more departments involved in R&D." (Q10)

"The matrix structure is an organisational support to the IPD, as it enables us to reunite our R&D team in an integrated way that is best suitable for each project… Our R&D staff located worldwide can join or be mandated in a project when [their] expertise is required… In this way, we can quickly and responsively launch projects with sufficient knowledge bases… it also contributes to improving the efficiency of our projects." (Q11)

"Human resource development [is] the key to the strategic transformation of our company… We paid much attention to it, in particular for [the] R&D department, where human resource and knowledge play the central role. We have kept taking actions to facilitate knowledge sharing and accumulation within our firm so that employee turnover and sackings will not have a critical impact on our R&D performance" (Q12)

"When we were able to make extra profit from overseas markets, we further realised the importance of our own technology… Not only in a sense that we could have better margin[s] when we develop a new technology. Rather, we realise[d] that we could fully meet more requirements of overseas customers, who usually have more specific and demanding needs." (Q14)

"Innovation [is] rooted in Huawei and our employees. We have changed a lot to cultivate a better structure that can facilitate our innovations… In particular, Huawei has to move [forward] and change [accordingly] as Huawei grows and the industry upgrades…" (Q16)

“We usually compare [ourselves] to wolves that are social animals living and hunting together… Collaboration, either with internal or external people, plays a critical role in our global innovation… We also encourage sharing. As for the globally dispersed R&D facilities, we have to facilitate knowledge sharing across regions, product lines and technology domains.” (Q18)

Unilever
“… [Each GDC’s] work is product category-specific and to develop a safe and qualified new formula of certain products to meet our standards of performance… We have several GDCs and work with internal competitions to win fund for R&D projects… [These approaches] helped us significantly increase the application of new technologies with more than 45% of the value of our innovation portfolio based on new technologies…” (Q5)

“Although big MNCs dominate the industry, local competitors are still very competitive, in particular for those who have deeply embedded with the local customers and institutions…We [the RDC] have to be responsive to local customers as well as local competitors. We provide competitive product features and analyse how local competitors position and feature their products in the market.” (Q6)

“…localisation dominates regional development activity. We make our global products ready [for] local markets… We involve supplier [supply] chain and marketing people at this stage, very much. We are in need of their insights [into] the local markets and manufacturing capacity in order to provide [the] best and most competitive solutions to localise our products… As [we are] widely dispersed, we also directly involve consumers in our innovation process…” (Q7)

“GDCs coordinate research labs and supervise regional centres. This coordination is difficult, in terms of diversified needs and technology. But [it] is essential, to enable knowledge transfer and integration [with such coordination]. We are not merely linked by our internal bidding. There are many supports and formally standardised procedures to facilitate the coordination, such as centralised planning and assembly.” (Q8)

“…With competition coming from all directions and at an ever-faster pace, we need to improve our innovation cycle times and ensure we roll out innovations faster and to more markets… [Thus,] our current global R&D begins with consumer insight and [we] respond [to] them with our innovative products… [This] is a more efficient way to accelerate the process to capture value from global markets… We also integrate our global R&D other departments to improve the performance. Over 70% of our innovations [from GRCs] are margin accretive.” (Q9)

“We need to balance local responsiveness and global efficiency in our global organisation. [The] GDC is the key to the balance. GDC(s) develop globally standardised solutions and fast transfer them to regional centres and they can easily [be] adjusted for local conditions.” (Q11)

Big Data and Supply Chain Management: A Marriage of Convenience?

Big data is the new "guy about town." Indeed, the buzz about Big Data and business intelligence (BI) as drivers of business information data collection and analysis continues to build steam. But it seems not everyone is taking notice. Whilst scholars in main are excited about the "fields of possibilities" big data and related analytics offer, in terms of optimising firm capabilities, supply chain scholars have been surprisingly quiet. In this work we hope to break this silence and we achieve this through a comprehensive survey of the literature with the aim of exposing the dynamics of big data analytics in the supply chain context. Our findings suggest that the benefits of a big data driven supply chain are many on the proviso that organisations can overcome their own myopic understanding of this socio-technical phenomenon. However, this is not to suggest a one-size fits all approach, our findings also reveal that adopting a big data strategy in the supply chain is a strategic decision and as such, given the idiosyncrasies of industries, firms should leverage these technologies in congruence with their core capabilities. Strategic fit between a firm core competences and its big data strategy creates causal ambiguity which can in turn lead to sustainable competitive advantage.

Digitalisation of Supply Chains: A dynamic capabilities perspective

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ABSTRACT

The purpose of this research is to understand how digital technologies in supply chains can be a source of competitive advantage. It is believed that digital technologies present dynamic capabilities that enable the firm to respond to quickly changing markets by delivering required information for supply chain decision-making in real-time. The methodology employed is case study research across a range of sectors involving 12 different companies/institutions. The approach taken includes understanding digital technologies in supply chains and employing a design structure matrix to investigate the relationship between supply chain decisions, required information and digital technologies by the means of case studies. The research has 4 key findings: 1) Definition of the concept of digitalisation, 2) 4 key digital technologies required for supply chain digitalisation, 3) Allocation of information to particular supply chain decisions, required technologies to capture this information and the source of the information and 4) Digital technologies only develop their full capabilities if employed jointly. A framework to assess whether particular digital technologies qualify as dynamic capabilities is proposed.

Keywords – Digitalisation, Digital technologies, Information flow, Decision-making, Dynamic capabilities, Digital technology assessment framework

1 Introduction

Digitalisation has become a widely talked about phenomenon of the 21st century. While companies seem to put all effort into digitalisation, the understanding of what it really means could not differ more: *"For some executives, it's about technology. For others, digital is a new way of engaging with customers. And for others still, it represents an entirely new way of doing business."* (Doerner & Edelman, 2015). The modern concept in its essence refers to a combination of digital technologies with automated and intelligent solutions that is expected to enable companies to create sustainable competitive advantage in a highly dynamic and environment. It is argued that digital technologies, such as big data analytics, can be such a source of competitive advantage (McAfee & Brynjolfsson, 2008; Wamba et al., 2016) by building dynamic capabilities (Fawcett, Wallin, Allred, Fawcett, & Magnan, 2011). However, despite substantial technology investments, many organisations have failed to obtain hoped-for improvements in supply chains (Fawcett et al., 2011; Klotz, 2016), which implies that it is not about purely investing in digital technology but about knowing *"when and where"* technology confers competitive advantage (McAfee & Brynjolfsson, 2008). Hence the question arises under which circumstances digital technologies can be a source of competitive advantage.

A major challenge in manufacturing companies is the lack of information availability required for decision-making, which prevents companies from making well-informed decisions in a timely manner to respond to quickly changing markets. It is believed that digital technologies can mitigate this challenge by providing the information required for decision-making in real-time, enabling companies to respond to and act in a highly dynamic environment. However, how can digital technologies provide required information and create sustainable competitive advantage and what technologies are required to do so? Questions that have yet to be answered.

Therefore, this research project aims at presenting an academic point of view on the extent of digitalisation paired with an industrial exploration of the concept of digital supply chains to answer the following research question:

How can digital technologies in supply chains be a source of competitive advantage?

1. *What does digitalisation mean in supply chains?*
2. *What information is required for supply chain decision-making and how do these information link to digital technologies?*
3. *How can competitive advantage be achieved through digital technologies from the perspective of dynamic capabilities?*

This research will address the questions by the means of case studies conducted in the "Technology & Research", "Pharmaceuticals & Chemicals" and the "Automotive" sector.
The dissertation is structured as follows: section 2 presents the theoretical background of the research. Section 3 describes the research methodology and design employed to answer the problem statement. Section 4 includes the data analysis and section 5 presents the discussion on the collected data. Section 6 concludes the dissertation, providing a summary of the key findings, limitations of this research, identified further research as well as theoretical and practical implications.

2 Theoretical background

2.1 Supply Chains, decision-making and information flow

The topic supply chain has been well covered in literature. Notable scholars described the supply chain as follows: *"The supply chain is a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer"* (Christopher, 1992). Beamon, 1998 described the supply chain as *"an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers"*. A more recent definition was attempted by Qrunfleh & Tarafdar, 2013: *"Supply chain spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption."*. While there has been absence of consensus on the definition of supply chains, the concept of the term has been similar amongst scholars over decades. The following definition of supply chain is adopted for the purpose of this research: *A supply chain is considered as a set of multiple linked entities that collaborate to deliver a product or service to the end-customer, spanning from raw material sourcing, manufacturing to delivering the product or service to the end-customer* (Beamon, 1998; Christopher, 1992; Hayes & Wheelwright, 1984; La Londe & Masters, 1994; Lambert & Cooper, 2000; Lummus & Alber, 1997; Mentzer, Keebler, Nix, Smith, & Zacharia, 2001; New & Payne, 1995; Qrunfleh & Tarafdar, 2013; Sarkis, 2012; Tang, 2006). The understanding of supply chains amongst scholars from the 1980s to the 2010s is depicted in Table 1.

Scholars / Object	Raw material Producers	Material Fabricators	Component parts producers	Manufacturer/Assembler	Wholesaler/Distributors	Retailers	Consumers
Hayes & Wheelwright, (1984)	x	x	x	x	x	x	x
La Londe & Masters, (1994)	x		x	x	x	x	
Christopher, (1992)	x: upstream and downstream linkages						x
New & Payne, (1995)	x	x	x	x	x	x	x
Lummus & Alber (1997)		x: Supplier		x	x	x	x
Beamon, (1998)		x: Supplier		x	x	x	
Lambert & Cooper (2000)		x: Supplier		x		x: Customer	
Mentzer, Keebler, Nix, Smith, & Zacharia, (2001)				x			
Tang, (2006)		x: Supplier		x	x	x	
Sarkis, (2012)		x: Supplier		x		x: Customer	
Qrunfleh & Tarafdar, (2013)				x			
Carter, Rogers, & Choi, (2015)		x: Supplier		x		x: Customer	

x: mentioned by the scholar in his/her research

Table 1: Components of supply chains

In order to control and steer a supply chain, decisions are made in companies on a daily basis. The next section reflects literature on supply chain decision-making.

Supply chain managers' roles are evolving into managing a complex structure in a rapidly changing and uncertain business environment (Manuj & Sahin, 2011). Supply chain complexity is reflected in the decision-making complexity, which is attributed to the volume and structure of information required to make informed decisions (Efstathiou, Calinescu, & Blackburn, 2002; Manuj & Sahin, 2011). Decisions can be of strategic, operational and tactical nature. Strategic decisions set the framework in which the company acts, tactical decisions are taken to satisfy strategic decisions and operational decisions are everyday decisions that serve the tactical decisions (Schmidt & Wilhelm, 2000). The time horizon of strategic, tactical and operational decisions are >5 years, up to 5 years and daily. Table 2 lists the decision and the decision level.

It is required to appreciate that there are much more decisions to be made in a company than reflected in the table. However, this literature review identified the most frequently made decisions in supply chains and will be confirmed or altered with empirical data in the course of this research.

Level	Description	Source
Strategic	Location of production facility	Revelle and Laporte, (1996); Jayaraman, (1999); Ganeshan & Harrison, (1995)
	Stocking points	Ganeshan & Harrison, (1995); Schmidt & Wilhelm, (2000)
	Sourcing points	Nair and Narasimhan, (2003); Narasimhan et al., (2003a, 2003b); Ganeshan & Harrison, (1995)
	Introduction of new products	Ganeshan & Harrison, (1995)
	Product portfolio	Ganeshan & Harrison, (1995)
	Make vs. Buy	Tagaras and Lee, (1996); Ganeshan & Harrison, (1995)
	Product-Plant allocation	Ganeshan & Harrison, (1995)
	Supplier-Plant allocation	Ganeshan & Harrison, (1995)
	Plant-Distribution Centre allocation	Ganeshan & Harrison, (1995)
	Distribution Centre-Customer allocation	Ganeshan & Harrison, (1995)
	Capacity of manufacturing facilities	Paraskevopoulos, Karakitsos, and Rustem, (1991); Ganeshan & Harrison, (1995); Schmidt & Wilhelm, (2000)
	Mode of transport (air, land, sea)	Chandra & Grabis, (2007); Ganeshan & Harrison, (1995)
	Routing and scheduling of material and equipment	Chandra & Grabis (2007), Márquez (2010)
Tactical	Coordination decisions for distribution system	Ma rquez (2010); Clements, Wilson & Bacanaru, (2006); Robinson and Satterfield, (1998)
	Demand planning	Hasan et al., (2011); Biswas, (2007); Ganeshan & Harrison, (1995)

	Procurement policies	Chandra & Grabis, (2007); Clark & Scarf, (1960); Anupindi & Akella, (1993), Ganeshan & Harrison, (1995)
Operational	Production scheduling	Márquez, (2010); Agrawal, Smith, & Tsay, (2002); Wang & Gerchak, (1996); Lee & Wei, (2001); Ganeshan & Harrison, (1995); Schmidt & Wilhelm, (2000)
	Workload balancing	Ganeshan & Harrison, (1995)
	Quality control measures	Ganeshan & Harrison, (1995)
	Inventory Management	Ma rquez, (2010); Moinzadeh & Aggarwal, (1997); Bagahana & Cohen, (1998); Ganeshan & Harrison, (1995); Schmidt & Wilhelm, (2000)

Table 2: Strategic, tactical and operational decisions

Well-informed supply chain decision-making requires specific information.

Efficient supply chains are characterised by real-time integration of information and collaboration (Xu, 2011). Information sharing via cross-enterprise information systems has been recognised to improve overall supply chain performance (Ball, Ma, Raschid, & Zhao, 2002; Xu, 2011). It appears that lack of data integration and hence availability of information is a major challenge why supply chains cannot be managed efficiently (Xu, 2011). The following table shows information flows in a supply chain. The classification into network, external and focal company environment was undertaken at the discretion of the researcher appreciating the nature of the information. This table includes the most frequently mentioned information flows in supply and will be validated and altered with empirical data in the course of the research.

Classification	**Description**	**Source**
Network	Customer profile (target group, potential sales)	Holweg & Pil, (2008)
	Retailer profile (location, capacity, price)	Holweg & Pil, (2008)
	Wholesaler profile (location, capacity, price)	Holweg & Pil, (2008)
	Supplier profile (location, capacity, price)	Holweg & Pil, (2008)
	Logistics provider (location, capacity, price)	Holweg & Pil, (2008)

External	Political situation in sales market	Dimitriadis & Koh, (2005); Holweg & Pil, (2008)
	Legislation and taxation	Dimitriadis & Koh, (2005); Holweg & Pil, (2008); Arntzen, Brown, Harrison and Trafton (1995); Ganeshan & Harrison, (1995)
	Infrastructural conditions	Holweg & Pil, (2008)
	Competitive landscape	Dimitriadis & Koh, (2005); Holweg & Pil, (2008)
	Consumer preferences & demand	Dimitriadis & Koh, (2005); Holweg & Pil, (2008); Lee, Padmanabhan, & Whang, (1997); Prajogo & Olhager, (2012)
	Maintenance cost	Dimitriadis & Koh, (2005); Holweg & Pil, (2008)
	Production labour	Dimitriadis & Koh, (2005)
	Technological advancement	Dimitriadis & Koh, (2005); Holweg & Pil, (2008)
Focal Company	Request for quotations & orders	Holweg & Pil, (2008); Prajogo & Olhager, (2012)
	Required raw material	Dimitriadis & Koh, (2005); Dong, Xu, & Zhu, (2009)
	Supply	Dong et al., (2009)
	Inter-firm logistics and despatch details	Dong et al., (2009); Holweg & Pil, (2008)
	Intra-firm logistics	Holweg & Pil, (2008)
	Monthly production schedules	Holweg & Pil, (2008)
	Report on inventory	Dong et al., (2009); Holweg & Pil, (2008)
	Report on supplier performance	Hittle & Leonard, (2011)
	Quality complaints	

Table 3 Information flows in supply chains

2.2 Supply Chain Digitalisation

Digitalisation is defined as the conversion of analogue information, such as text, into digital information (Princeton University, n.d.). Supply chain digitalisation refers to the adoption of inter-organizational systems by business organisations to collaborate and transact with their external partners (e.g., key suppliers and customers) along their value/supply chains (Barua, Konana, Whinston, & Yin, 2004; Rai, Brown, & Tang, 2009; Rai, Patnayakuni, & Seth, 2006; Xue, 2014), in other words: conducting day-to-day business activities with supply chain partners via digital information exchange (Barua et al., 2004). Even though different definitions appear in literature, the extent of supply chain digitalisation remains elusive and opinions differ.

Supply chain digitalisation is often considered being risky, primarily because the external parties and environment that organisations need to interact with are beyond their controls (Xue, 2014). Furthermore, it is a concept that requires commitment of all partners along the entire supply chain, from raw material supplier to end-customer (Barua et al., 2004). Firms with higher levels of digitalisation enjoy better business performance due to dynamic capabilities being created through digital technologies (Barua et al., 2004; Fawcett et al., 2011). Companies have made significant investments in digital technologies to leverage competitive advantage; however, not all have reaped the hoped-for benefits (Fawcett et al., 2011).

Prevalent technologies that promote real-time information capturing and exchange today include mobile technologies, big data, social media and cloud computing (Bhimani & Willcocks, 2014). An overview of the most influential technologies in digitalisation of supply chains is given in the next subsection.

It is worth noting that the technologies and concepts are on different levels of granularity. The reason being that there is no clarity in literature as to how to distinguish and classify digital technologies used in supply chains. However, a preliminary classification of technologies was undertaken at the discretion of the researcher appreciating their different characteristics. The classification is presented in Table 4.

Classification	**Characteristics**
Infrastructure	Overall system of digital supply chain
Cyber-physical systems	*system that integrates computation, communication and physical processes, such as transportation networks*
Information and Communication Technologies	*transfer of information through radio, television, mobile phones, computers (through hard-and software), networks, and satellite systems*
Business Intelligence	Acquisition and processing of data into meaningful information and delivering the right information to the right people at the right time
Big Data Analytics	*analytical techniques to capture and process big data (high volume, high velocity, high variety)*
Artificial Intelligence	*supports engineering goals such as, developing intelligent agents, formalising knowledge and mechanising reasoning*
Data Virtualisation	*integrates different sources of data*

Cloud Computing	Integration of systems into a network so that software systems and data can take use of it
Clouds	*data storage*
service-oriented architecture	*integrates services different companies choose to make available*
Mobile cloud computing	*data storage and data processing outside the mobile device, e.g. in a cloud*
Social Media	Communication with customers through a set of tools and strategies such as blogs, collaborative projects (such as Wikipedia), social networking sites (such as Facebook) and content communities (such as YouTube)
Enterprise Systems	Set of software applications that allow organisation of accounting and control, manufacturing and distribution, sales and order, human resources and management reporting
Track & Trace	Capture and transfer information about location and state of objects
RFID	*Tracking and storing information about a physical object's nature and location*
GPS	*recording time and positional characteristics*
Wireless sensor networks	*fine-granular collection of information in the physical world and transfer to a wireless base-station*
Automation	Automated devices assisting predominantly shop floor activities
Botsourcing	*robots to replace human workers*
Automated guided vehicle systems	*automated transport of material*
Gamification	*enriching products, services and information systems with game-design elements in order to positively influence motivation, productivity, and behaviour of users*
Augmented reality	*provides assistance to operations in industries, for example assembly guidance*
3D Printing	*quick creation of parts/products, especially for prototyping*

Table 4: Classification of Technologies according to their characteristics

2.3 Competitive advantage from a dynamic capabilities perspective

A dynamic capability is the firm's potential to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base (Barreto, 2010). The dynamic capabilities theory builds upon the theoretical foundations of the resource-based view provided by Schumpeter (1934), Penrose (1959), Williamson (1975, 1985), Barney (1986), Nelson and

Winter (1982), Teece (1988), and Teece et al. (1994) (D. J. Teece, Pisano, & Shuen, 1997). Resource-based view suggests that a company can establish competitive advantage by creating firm-specific, strategic resources or capabilities (Barney, 1991; Collis & Montgomery, 1995; Hoopes, Madsen, & Walker, 2003; D. J. Teece et al., 1997).

While the resource-based view sees competitive advantage in firm-specific resources, dynamic capabilities theory takes the view that competitive advantage lies in processes, positions and paths. Processes are *"the way things are done"*, positions are technology, intellectual property, complementary assets, customer base and external relations (D. J. Teece et al., 1997) and paths are strategic alternatives available. Resource-based view suggests how competitive advantage can be achieved, while dynamic capabilities theory focuses on how to sustain competitive advantage. The winning companies are the ones that can effectively redeploy internal and external resources (D. J. Teece et al., 1997) to enable the business to adapt to a dynamic environment (Prahalad & Hamel, 1990). The characteristics of dynamic capabilities described by leading scholars in the field are illustrated in Table 5.

Scholars	**Characteristics of dynamic capabilities**	Competence to create new products and processes	Competence to respond to changing markets	Competence to use resources to create market change	Competence to create, extend, modify resource base
D. Teece & Pisano, 1994		x	x		
D. J. Teece et al., 1997			x		
Eisenhardt & Martin, 2000			x	x	x
Zollo, M., Winter, 2002					x
Zahra, Sapienza, & Davidsson, 2006					x
Helfat et al., 2009		x			x
Barreto, 2010			x	x	x
x: mentioned by the scholar in his/her research					

Table 5 Characteristics of dynamic capabilities

2.4 Problem statement

The literature presents the concept of supply chains, supply chain decision-making, information flow, digitalisation and dynamic capabilities. It is acknowledged that supply chain decision-making becomes increasingly complex due to globalisation and a rapidly changing environment. Supply chain complexity can be attributed to the volume and structure of information. Literature also recognises that lack of information availability is a major challenge in supply chain decision-making. However, the relationship between particular supply chain decisions, required information and missing information remains unclear. While lack of information has remained a challenge in supply chain decision-making, a concept has risen to prominence over the last couple of years that can mitigate this challenge: digitalisation of supply chains. This concept is believed to provide comprehensive information along the supply chain in real-time and provide competitive advantage by enabling quick decision-making. However, the concept of digitalisation remains elusive. It is also unclear what particular digital technologies can deliver the information required for informed supply chain decision-making and under what circumstances digital technologies in supply chains present a source of competitive advantage.

Hence, the following research question is inquired:

How can digital technologies in supply chains be a source of competitive advantage?

1. *What does digitalisation mean in supply chains?*
2. *What information is required for supply chain decision-making and how do these information link to digital technologies?*
3. *How can competitive advantage be achieved through digital technologies from the perspective of dynamic capabilities?*

To address the research question and its sub-questions, a suitable research methodology was developed and is presented in section 3.

3 Methodology

The goal of the research is to identify how digital technologies in supply chains can be a source of competitive advantage. To address this question, the linkage between the following three topics needed to be produced: (a) what is the concept of digitalisation and what digital technologies are available for supply chain digitalisation, (b) what information is required in supply chain decision-making and how can this information be attributed to particular supply chain decisions and (c) what are the qualifying criteria for digital technologies to be considered as dynamic capabilities. An appropriate research methodology was developed and is structured around the topics (a), (b) and (c). The research methodology is introduced in Figure 1.

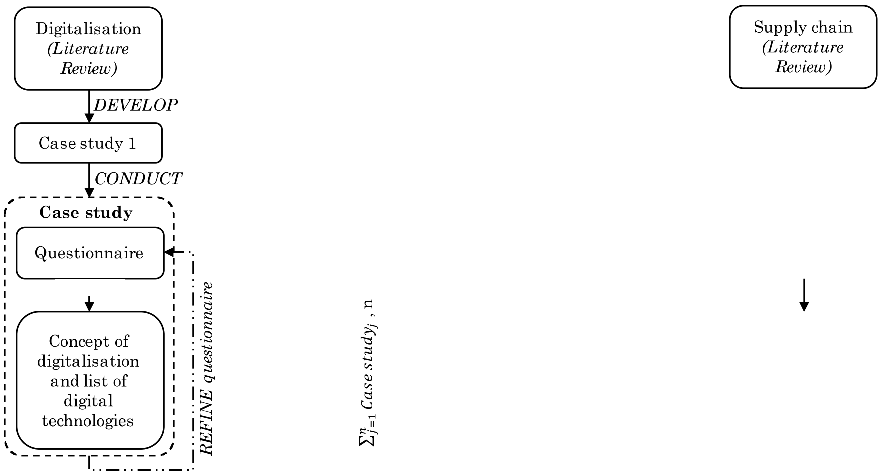

Figure 1: Research Framework

The research was split into three phases: I. Define & Design, II. Prepare, Collect, Analyse, III. Analyse & Conclude.

The first phase of the research included a literature review on digitalisation, supply chains and dynamic capabilities as well as the development of case studies. Qualitative case study research with various companies from different industries was employed due to the focus of the research on contemporary events, no requirement to control behavioural events and the nature of the research question (Yin, 2009). Case study selection criteria were developed according to which companies were selected. The companies with which case studies were conducted are displayed in Figure 2.

Organisations	Case 1	Case 2	Case 3
Audi AG			x
Bayer AG		x	
Boehringer Ingelheim GmbH		x	
Bosch Software Innovations GmbH	x		
Fraunhofer Institute for Integrated Circuits	x		
Fraunhofer Institute for Material flow and Logistics	x		
Institute for Industrial Management (RWTH Aachen)	x		
Jaguar Land Rover Ltd.			x
LANXESS AG		x	
Merck KGaA		x	
Volkswagen AG (VW)			x
World Economic Forum	x		

Figure 2: Interviewed organisations

Phase II encompassed the preparation, data collection and the analysis of gathered data. The tools employed in the case studies conducted were semi-structured interviews and a binary Design Structure Matrix (DSM). Semi-structured interviews were chosen to allow for flexibility in the covered topics due to the exploratory nature of the research (Yin, 2009). The DSM is generally used to find out relations in a complex system (Eppinger & Browning, 2012). This is well suited to identify the relationship between information, supply chain decisions, digital technologies and the source of information. The DSM employed is depicted in Figure 3. The following explanations are required to understand the DSM:

- Information as well as strategic, tactical and operational supply chain decisions displayed in the matrix were identified from literature (section 2.1 and 2.2).
- Classification of information into focal company, external and network environment was undertaken at the researcher's discretion according to the nature of the information and verified with interview participants.
- Technologies were identified from case study 1.
- Source of information was based on interview participants' opinions.

			SUPPLY CHAIN DECISIONS																					TECHNOLOGY										SOURCE OF INFORMATION								
			Strategic															Tactical			Operational																					
			Location of production facility	Stocking points (Where is stock stored, e.g. Distribution Centers)	Sourcing points	Introduction of new products/Productportfolio	Make vs. Buy	What plants to produce the products in	Capacity of manufacturing facilities (nur didier)	Risk Management & Contingency	Allocation of suppliers to plants	Plants to Distribution Centers	Distribution centers to customer	Production Planning (Master)	Distriubtion requirements planning	Mode of transport (air, land, sea)	Routing and scheduling of material and equipment	Demand planning	Procurement policies	Coordination decisions for distribution system	Production scheduling	Workload balancing	Inventory Management	Big Data Analytics (descriptive, predictive, prescriptive)	Cloud & Platforms	Cyber-physical systems	MES &ERP	Sensors	Track & Trace (RFID, GPS)	3D Printing	Automation	Virtual Reality	Social Media	Market	Raw material producer	Component producer	Direct supplier	Manufacturer/Assembler	Wholesaler/Distributor	Retailer	Consumer	Transportation Company
INFORMATION	NETWORK ENVIRONMENT	Customer profile (target group, potential sale)																																								
		Retailer profile (location, capacity, price)																																								
		Wholesaler profile (location, capacity price)																																								
		Supplier profile (location, capacity, price)																																								
		Logistics provider (transportation rates)																																								
	EXTERNAL ENVIRONMENT	Political situation in sales market																																								
		Legislation and taxation																																								
		Infrastructural conditions																																								
		Competitive landscape																																								
		Consumer preferences & demand																																								
		Maintenance cost																																								
		Production labour																																								
		Technological advancement																																								
	FOCAL COMPANY ENVIRONMENT	Request for quotation & order																																								
		Required raw material																																								
		Supply																																								
		Inter-firm logistics & despatch details																																								
		Intra-firm logistics																																								
		Monthly production schedules																																								
		Report on inventory																																								
		Reports on supplier performance																																								
		Quality complaints																																								

Figure 3: Design Structure Matrix

Additional tools employed in Phase II and III involved

- Heat maps, to identify and visualise patterns, and
- Data displays to demonstrate results

as proposed by Miles et al., 2014. Phase III involves the cross-case analysis from all case studies and literature as well as the conclusion.

To ensure a high quality of research, construct validity, internal validity, external validity and reliability tests were employed throughout the research as suggested by Yin, 2009. The phases are further explained in the following subsections.

4 Case Analysis

The following table presents the potential interview participants identified for particular digital technologies.

Digital Technology	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**Potential for Companies**
Analytics		x				x	x	• Support for strategic decision-making through descriptive (data gathering), predictive (prediction of future events) and prescriptive (analytical guidance for decision-makers) analytics (T6)
Cloud & Platforms		x	x			x	x	• Clouds: data storage and management (T2); information exchange (T3) • Platforms: data processing and generation of value added services; licensing services for data analyses (T2) • Possibility to collect data on a more granular level with regards to space and time, increased data availability (T6)
Cyber-physical systems		x		x	x	x	x	• Exchange of information between intelligent objects and their environment (T2) • Enables prognosis ability, control ability and after all self-optimisation of the supply chain (T2) • Improved agility of supply chain and quick reaction to market demand since it enables the scale of production capacity by quickly adding or eliminating machinery in the production cycle (T4, T5) • Enables both horizontal and vertical integration (T6)
MES & ERP		x	x				x	• Current research focuses on systems that can integrate ERP and MES to improve data handling (T2, T3) • In combination with Track & Trace: data collected with Track & Trace systems can be automatically transferred to the ERP & MES system and trigger certain actions dependent on the state and location of the product. F.ex. automatically trigger distribution when product is “ready to be shipped” (T2)
Sensors	x			x	x	x		• End-to-end visibility and control of supply chain (T1) • Capture real-time information in supply chain (T4, T5)
Track & Trace		x	x			x	x	• Real-time information about state and location of an object (T2,T3)

								• Fast and easy access and exchange of information at any location in the supply chain (T2) • Improves production and transport logistics (T6)
Social Media				x	x		x	• Information about customer satisfaction, requirements, expectations, etc. (T4, T5)
3D Printing	x		x				x	• Participants mentioned this concept but did not clearly state the potential for companies
Automation	x					x	x	• Autonomous production and delivery of product to the doorstep of the customer without human interaction at some point in the future (T1) • Operational decisions can be very well automated (T6)
Virtual Reality				x	x			• Provision of information and interaction between data layer and users (f.ex. support of picking activities for warehouse personnel) (T4, T5)

Tx = Technology & Research Participant x

Table 6: Statistics of interviews regarding digital technologies and potential for companies

The following table presents the concept of digital supply chains, benefits and barriers of digitalisation.

No.	Digital Supply Chains	T1	T2	T3	T4	T5	T6	T7	P1	P2	P3	A1	A2	A3
#1	*Interconnectedness of cyber-physical systems*	x	x	x	x	x		x	x			x	x	
#2	*Vertical and horizontal information exchange*		x	x	x	x		x	x	x		x		
#3	*Automation of processes*	x			x	x		x					x	x
#4	*Collection and access to real-world information in real-time*		x	x	x	x		x	x	x	x	x	x	
#5	*Reconfiguration of mainly existing technologies*	x			x	x	x	x	x	x				

No.	**Benefits of Digitalisation**													
#1	*Real-time information tracking and sharing*		x					x	x	x	x	x	x	x
#2	*Process improvements*				x	x			x	x	x	x	x	
#3	*Data transparency (end-to-end)*	x			x	x	x	x		x	x	x	x	x
#4	*Emerging of new business fields*				x	x			x					
#5	*Increased decision-making velocity*										x			
#6	*Improved productivity on the shop floor*											x	x	x
	Barriers for digitalisation													
#1	*Showing stakeholders benefit*		x	x	x	x								
#2	*Data security*		x	x	x	x		x	x			x		x
#3	*Trust*		x	x				x				x		
#4	*Lack of expertise in implementation*	x			x	x			x					
#5	*Lack of vision of concept*	x					x			x				
#6	*Lack of financial resources*	x						x		x			x	x

Tx = Technology & Research Participant number x; Px = Pharmaceuticals & Chemicals Participant number x; Ax = Automotive Participant number x;
x = mentioned by respective participant

Table 7: Concept of digital supply chains, benefits and barriers of digitalisation

Figure 4 presents the relationship between supply chain decisions, information, technology and source of information.

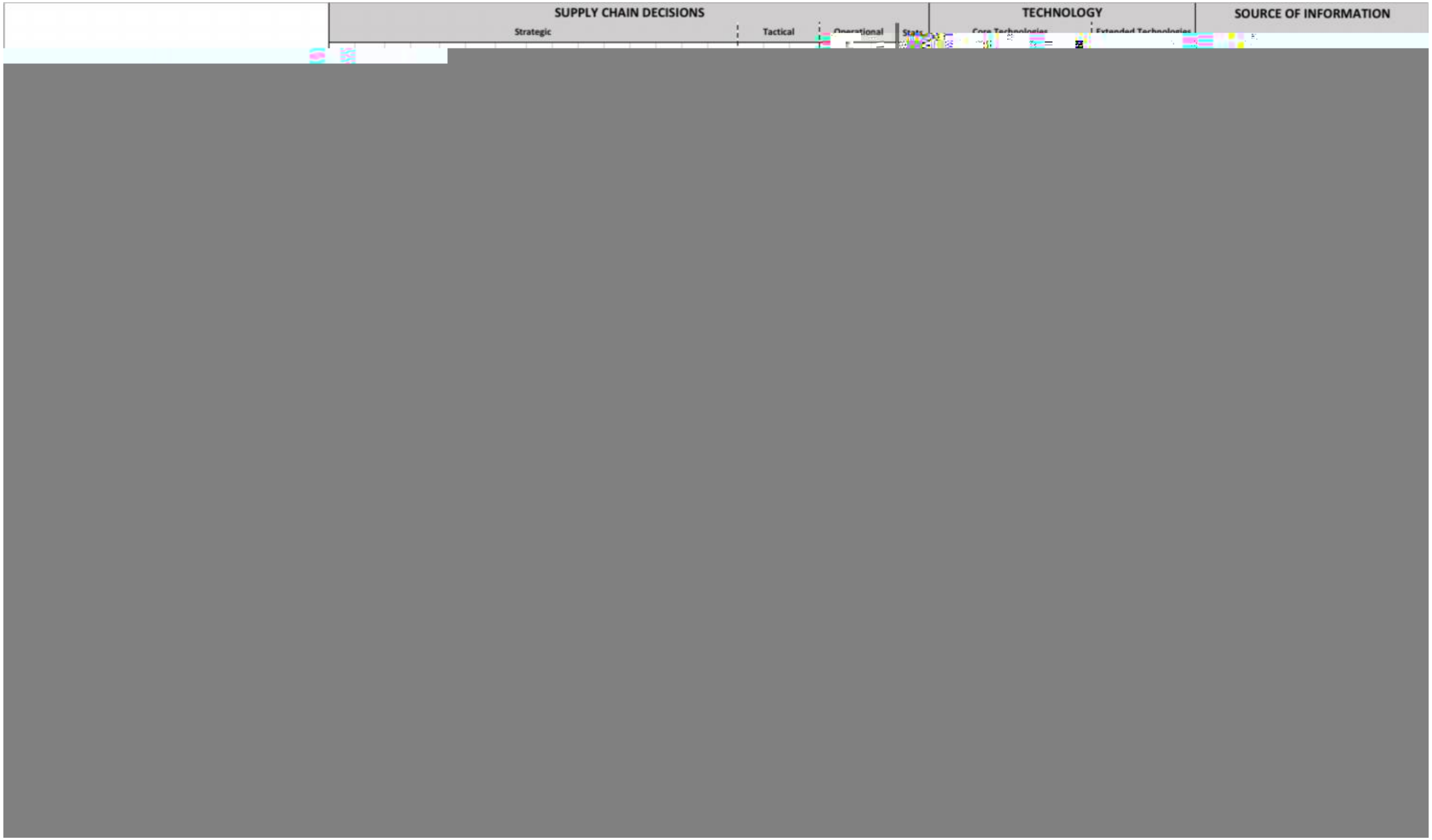

Figure 4: Relationship between Information, Supply Chain Decisions, used Technology and Source of Information

5 Discussion

In order to answer how digital technologies can be a source of competitive advantage in supply chains, the discussion includes the clarification of the concept of digital supply chains, the link of required information for decision-making to digital technologies, their source and the reasoning under which circumstances digital technologies can be a source of competitive advantage from a dynamic capabilities perspective.

5.1 Digital Supply Chains

Digitalisation is defined as the conversion of analogue information, such as text, into digital information. This view from literature was confirmed by interview participant T1. According to another interview participant (A2) digital *"is simply 0 or 1"*. This vague definition requires a context specific interpretation of the concept of digitalisation. The main implication of context-specificity is the requirement to apply differing technologies. In this research, digitalisation in the context of supply chains is considered.

The views on digitalisation of supply chains presented in academia appear to be of a generic nature as opposed to the views in industry, which attribute precise characteristics to the concept. According to industry, digitalisation of supply chains is structured around interconnectedness between systems, vertical and horizontal information exchange, collection and instant access to real world information in real time and combination of different technologies, as demonstrated in Table 7. This characterisation implicitly incorporates the academic perspective: the idea of inter-organisational collaboration and exchange of information is in line with the interviewees' opinions in that *"the information exchange happens vertically, within a company, and horizontally, across supply chain partners, such as suppliers, manufacturers, end-customers, etc."* (T2, T3) and *"Organisational and processual linkages of procedures in the entire supply chain are a key component of a digital supply chains"* (T4, T5). Hence, the definition in literature presents a fraction of the characteristics interview participants declared. The following definition of digital supply chains is suggested based on academic and industrial perspectives:

Digital supply chains are interconnected cyber-physical systems capable of storing, processing, providing and vertically and horizontally exchanging information along the entire supply chain in real-time by the means of enabling digital technologies.

5.2 Information required for informed decision-making and linking digital technologies to information

Information transparency and availability is crucial for informed decision-making. *"Decisions are made every day"* (A2) and require particular information that include information from the categories **focal company**, **network** and **external** environment. The importance of information availability is stressed by the fact that the majority of the interview participants mentioned *"end-to-end data transparency"* (T1, T4, T5, T6, P1, P2, P3, A1, A2, A3) and *"real-time information tracking and sharing"* (T2, P1, P2, P3, A1, A2, A3) as the expected benefits from digitalisation. The importance of establishing not only partial transparency, as it is currently experienced by most interview participants (P1, P2, P3, A2, A3) in their company, but end-to-end data transparency becomes apparent when considering the nature and source of the information in Figure 4: The majority of supply chain decisions identified, be it on a strategic, tactical or operational level, require information from all three information categories: **Network Environment, External Environment** and **Focal Company Environment**. **Network environment**-level information is required the most, which can be explained by acknowledging that manufacturing companies by implication are generally collaborating with supply chain partners to produce and deliver a product. Hence, much information required for supply chain decision-making will be impacted by supply chain partners about which information needs to be captured. Besides the importance of information about the network environment, obtaining information about the **external environment** appears to be similarly important to companies. Especially consumer preferences & demand, infrastructural conditions as well as legislation appear to be crucial for supply chain decision-making on all levels in this respect. This pattern can be understood by taking into account the nature of the companies interviewed. Manufacturing products and delivering them to the end-customer stresses the importance of knowing precisely the desired products and quantities to adjust production accordingly and ensure a high service-level. Generating knowledge about consumer preferences & demand is therefore inevitable. Likewise, products need to be delivered to the customer, usually by one of the following modes of transportation: land (road and rail), sea, air (P1, P2, P3, P4). Especially the land transportation seems to be requiring the knowledge about the local infrastructure because this influences mode of transportation, cost, delivery time and implicitly customer satisfaction. Figure 4 suggests that legislation is equally important. The nature of this information requires the explicit distinction between pharmaceutical and chemical and automotive industry. *"Production of pharmaceutical products is highly regulated and* *processes need to be documented rigorously. Each production process and product needs to be validated before it can be produced and sold to the consumer. This process usually takes a couple of years."* (P1). This implies that legislation in the respective market is crucial for sales since it determines a) the duration of the approval process and b) the Start of Production (SOP). This will become relevant when deciding which geographical and/or product markets to enter in the researcher's opinion.

In terms of **focal company environment** information, it appears that required raw material and interfirm logistics & despatch details are very important. Certainly, knowing the raw material requirements and logistics details are crucial in determining the delivery time for the customer and hence ensure high customer satisfaction in this respect.

As previously discussed, information required the most for identified supply chain decisions is not generated within the focal company, forcing the company to capture this information in either the network or external environment. Certainly, it could be argued that the information presented in Figure 4 might reveal this pattern due to the nature of the information considered; however, the emphasis lies on the fact that much information required for important decisions is not available within the boundaries of the focal companies but requires information exchange along the entire supply chain. This gives reasoning why interview participants mentioned that end-to-end data transparency is crucial.

It becomes apparent that the market is the most frequently mentioned **source** of the information addressed. This implies that companies require capabilities to collect market information. The lack of information availability about the market becomes apparent by recognising the inaccuracy in demand planning, which is information available on the market. *"End-to-end transparency of demand establishes better forecast accuracy. This would allow for almost no stock out and a high service level"* (P2). Therefore, having access to market information is crucial for high service levels, low inventory and quick decision-making (P2, P3).

This previous section discussed that information identified from literature and confirmed with interviewees is crucial on the strategic, tactical and operational level. The information required for most decisions lies in the network and external environment. The source of this information is the market, where information is uncertain. Companies are required to collect information outside the boundaries of the companies. While collecting information contributes one step towards data transparency along the supply chain, it has to be acknowledged that the uncertainty of information might affect its quality. However, "*High quality and granularity of information is crucial for decision-making. Digital technologies support this"* (T6).

How can fine-granular and precise information be captured in real-time to support supply chain decision-making? It is evident from Figure 4 that companies are currently capturing **focal company environment** information with MES and ERP systems. However, the required **network** and **external environment** information are not systematically captured in any of the interviewed companies. It appears that capturing network information, hence data transparency along the supply chain, involves focusing on building trust and establishing data security between supply chain partners (P2, P3, P7, A1) while capturing external environment information seems to be a matter of technological feasibility, which is fundamentally different. Building trust and ensuring data security involves participation of partners in the supply network and is a prerequisite for capturing network information. Hence, the challenge is to "*convince supply network partners of the benefits of digitalisation"* (T3).

The following table compiles the suitability of the digital technologies identified during the course of the research for the provision of required information for supply chain decision-making in alphabetical order.

Digital Technology	Captures required information	Information captured	Justification
3D Printing	No	N/A	• Technology employed in production processes, which allows new design perspectives in terms of material, shape and internal structure of products. • Neither interview participants from technology & research institutions nor from pharmaceutical and chemical nor from automotive companies clearly stated the potential.
Big Data Analytics	Yes	Network and external environment	• Large amounts of diverse information can be gathered and processed quickly, which makes this technology particularly suitable to collect network and external information due to the amount and dynamic of the information. This view is supported by one participant claiming: *"data analytics also helps gathering external data"* and "*adjust production to last demand changes"* (P2). Another participant takes the view that *"gathering and provision of information can be supported by applying descriptive, predictive and prescriptive analytics"* (T6) • All participants that referred to big data analytics mentioned the technology in the context of network and external environment.
Cloud computing	No	N/A	• Represents a combination of various technologies as identified from literature and presents a platform on which data can be uploaded and processed to extract meaningful results (T2, T3, T6). Hence, cloud computing does not seem to present a digital technology to gather but rather to store and provide information captured by other digital technologies.
Cyber-physical system	No	N/A	• Defined as the systems that offer integrations of computation, networking and physical processes as identified from literature. (T2, T6). Examples of cyber physical systems identified in literature include transportation networks and distribution networks. Hence, it appears that the terminology "cyber-physical systems" refers to the integration of the digital technologies that capture the information (T4, T5); it is not the cyber physical system itself.

MES & ERP	Yes	Focal company environment	• Integrates information about accounting and control, manufacturing and distribution, sales and orders, human resources and management reporting, as identified from literature (T2, T3).
Robotics	No	N/A	• Robotics can be used for the *"autonomous production and delivery of products without human interaction"* as identified by interview participant T1. However, it appears to be suitable for shop floor digitalisation with regards to process improvements (T6).
Sensors	Yes	Focal company environment	• Participants see the potential of the technology in promoting end-to-end visibility and control of supply chains (T1) and provision of real-time information in the supply chain (T4, T5). Hence, sensors appear to represent a track & trace technology. Therefore, sensors will not be regarded separately but as part of Track & Trace in the course of the research.
Social Media	Yes	External environment	• It is a set of tools and strategies to communicate with customers, especially through blogs, collaborative projects (such as Wikipedia), social networking (such as Facebook) and content communities (such as YouTube) as identified from literature. • P1 acknowledged the potential in the following area: *"Company external data, such as customer data, is not readily available. Other solutions need to take care of collecting this information and make it available to companies. Social media would be such a solution with which structured data could be collected"*.
Track & Trace	Yes	Focal company environment	• Track & Trace technologies (RFID and GPS) store information about a physical object and its location. It can be used for inventory tracking and identification of objects as identified from literature. The identified potential for companies lies in the provision of focal company environment information (T2, T3).
Virtual Reality	No	N/A	• Virtual Reality is characterised by illustrating the real world enhanced with sound, video, GPS data, etc. and provides assistance to operations in industries, as identified from literature. • Interview participants T4 and T5 gave picking glasses to *"support picking activities for warehouse personnel"* as example. Hence, it appears to be a technology of operational nature.

Table 8: Digital Technology Assessment

The characteristics of the digital technologies identified in the literature review and the discussion in Table 8 provide the insights required to build the linkage between particular information required for decision-making and the digital technology that can deliver it. The steps involve:

1. Allocating particular information to particular supply chain decisions (conducted with the Design Structure Matrix during the interviews (for results refer to Figure 4))
2. Allocating particular information to particular source (conducted with the Design Structure Matrix during the interviews (for results refer to Figure 4))
3. Allocating particular information to digital technologies (refer to Figure 5)

Figure 5 presents the results.

INFORMATION		SUPPLY CHAIN DECISIONS																			
		Strategic														Tactical			Operational		
		Location of production facility	Stocking points (Where is stock stored, e.g. Distribution Centers)	Sourcing points	Introduction of new products/Productportfolio	Make vs. Buy	What plants to produce the products in	Capacity of manufacturing facilities (nur didier)	Allocation of suppliers to plants	Plants to Distribution Centers	Distribution centers to customer	Production Planning (Master)	Distriubtion requirements planning	Mode of transport (air, land, sea)	Routing and scheduling of material and equipment	Demand planning	Procurement policies	Coordination decisions for distribution system	Production scheduling (local)	Workload balancing	Inventory Management
NETWORK ENVIRONMENT	Customer profile (target group, potential sale,)		x	x	x	x		x			x	x	x	x	x	x		x		x	x
	Retailer profile (location, capacity, price)		x	x	x	x					x		x	x	x	x		x		x	x
	Wholesaler profile (location, capacity price)		x	x	x	x		x		x	x		x	x	x	x		x		x	x
	Supplier profile (location, capacity, price)		x	x	x	x			x					x	x		x	x			x
	Logistics provider (transportation rates)	x	x	x		x			x	x	x	x	x	x	x			x			
EXTERNAL ENVIRONMENT	Political situation in sales market	x			x										x	x	x	x			
	Legislation and taxation	x	x	x	x	x								x	x	x	x	x			x
	Infrastructural conditions	x				x	x	x	x	x	x		x	x	x	x		x			
	Competitive landscape				x			x			x	x				x		x			
	Consumer preferences & demand				x			x	x	x	x	x	x	x	x	x		x		x	x
	Profitability	x	x	x	x	x	x	x													
	Required approval studies	x	x	x	x	x	x														
	Potential for pharmaceutical transfer					x	x														
	Maintenance cost	x				x	x	x				x						x			
	Production labour	x				x	x					x						x			
	Technological advancement	x				x	x					x									
FOCAL COMPANY ENVIRONMENT	Request for quotation & order											x			x		x	x		x	
	Required raw material								x			x			x		x	x			x
	Supply	x						x	x			x				x	x				
	Inter-firm logistics & despatch details								x	x	x			x	x						
	Intra-firm logistics													x	x			x			x
	Monthly production schedules					x						x						x	x	x	
	Report on inventory											x						x			x
	Reports on supplier performance			x					x								x				
	Quality complaints			x		x	x		x								x	x		x	

INFORMATION		TECHNOLOGY				SOURCE OF INFORMATION								
		Big Data Analytics (descriptive, predictive, prescriptive)	MES &ERP	Track & Trace (RFID, GPS)	Social Media	Market	Raw material producer	Prestage producer	API producer	Manufacturer/Assembler	Wholesaler/Distributor	Retailer	Consumer	Transportation Company
NETWORK ENVIRONMENT	Customer profile (target group, potential sale,)	x											x	
	Retailer profile (location, capacity, price)	x										x		
	Wholesaler profile (location, capacity price)	x									x			
	Supplier profile (location, capacity, price)	x					x	x	x					
	Logistics provider (transportation rates)	x												x
EXTERNAL ENVIRONMENT	Political situation in sales market	x			x	x								
	Legislation and taxation	x				x								
	Infrastructural conditions	x				x	x	x	x		x	x		x
	Competitive landscape	x				x					x	x		
	Consumer preferences & demand	x	x		x	x				x			x	
	Profitability	x	x			x				x				
	Required approval studies	x				x								
	Potential for pharmaceutical transfer	x	x			x								
	Maintenance cost	x	x			x								
	Production labour	x	x			x								
	Technological advancement	x				x								
FOCAL COMPANY ENVIRONMENT	Request for quotation & order		x								x	x		
	Required raw material		x							x				
	Supply		x				x	x	x					
	Inter-firm logistics & despatch details		x	x			x	x	x		x	x		x
	Intra-firm logistics		x	x						x				
	Monthly production schedules		x							x				
	Report on inventory		x							x				
	Reports on supplier performance		x					x	x	x				
	Quality complaints		x		x	x					x	x	x	

Figure 5: Relationship between Information, Supply Chain Decisions, suggested Technology and Source of Information

5.3 Digital technologies in supply chains as source of competitive advantage: a dynamic capabilities view

Dynamic capabilities theory takes the view that competitive advantage lies in processes, positions and paths. As identified from literature, technology can be considered as a position since positions refer to assets companies possess. In order for the digital technologies identified to represent a dynamic capability, they need to fulfil the criteria suggested by the theory: competence to create new products and processes, competence to respond to rapidly changing markets, competence to use resources to create market change and competence to create, extend or modify the resource base of the company.

Whether or not the relevant digital technologies identified represent a dynamic capability is discussed in Table 9.

Digital Technology	Dynamic Capability	Justification
Big Data Analytics	Yes	• Companies will be able to collect and process information about their environment and derive appropriate actions rapidly. As one interviewee mentioned: *"if we have a competitor that is in a stock out situation, we can get this information quickly and adjust our production to satisfy the additional demand."* (P2). → Competence to respond to rapidly changing markets and competence to use resources to create market change by taking over market share. • *"Additional values to customers enabled by information availability can be generated"* as identified from interview participants T4 and T5. → Competence to create new products and processes.
MES & ERP	Yes	• Can be integrated with Track & Trace technologies to create a new resource: *"Tracking and tracing information of objects can be shared with enterprise systems, such as ERP or MES. These enterprise systems can then trigger appropriate actions, dependent on location or state of the object, such automatically trigger distribution when product is "ready to ship""* (T2). This would enable the company to increase supply chain velocity, which is an important factor in a quality, cost and delivery time driven market environment. → Competence to create, extend or modify resource base.
Track & Trace	Yes	• Tracking of objects "*enables us to know exactly where every raw material and product is"* (P3). This would allow the company to rapidly react to fluctuating demand through optimised workload balancing and rapid response to increasing demand, for example. Furthermore, optimised workload balancing also enables companies to respond to customer preferences quickly by being able to introduce additional production processes to produce adapted or new products due to available capacity. → Competence to respond to rapidly changing markets and competence to create market change.
Social Media	Yes	• Social media integrated with MES & ERP systems could improve demand planning by capturing customers' opinions through their interaction on the internet. It can also help improve customer service as one interviewee identified: *"It is extremely important to know about customer satisfaction to be able to react quickly, assist the customer if required and provide a good service."* (P1) → Competence to create market change by quickly adapting customer wishes and therefore alter products or services.

Table 9: Digital technology assessment from a dynamic capabilities perspective

All digital technologies identified and required for providing information for decision-making present a dynamic capability. However, it is the seamless integration of technology into a cyber-physical system that provides **focal company, network** and **external environment** information extent (T2, T3, T4, T5, P1, P2, P3, A1, A2) and creates competitive advantage.

6 Conclusion

Digital technologies integrated into a system capable of delivering focal company, network and external environment information help companies sustain competitive advantage in a highly dynamic environment.

In order to come to this conclusion, three case studies were conducted investigating (a) the concept of digitalisation, (b) identifying required information for supply chain decisions and (c) linking digital technologies to required information. 14 interviews in 12 different institutions across three different industries were carried out. A cross-case analysis and the incorporation of a key theoretical concept describing how to create sustainable competitive advantage revealed under what circumstances identified technologies present a dynamic capability. The following framework is suggested to evaluate whether a particular digital technology has the potential to qualify as dynamic capability on the basis of the analysis and discussion.

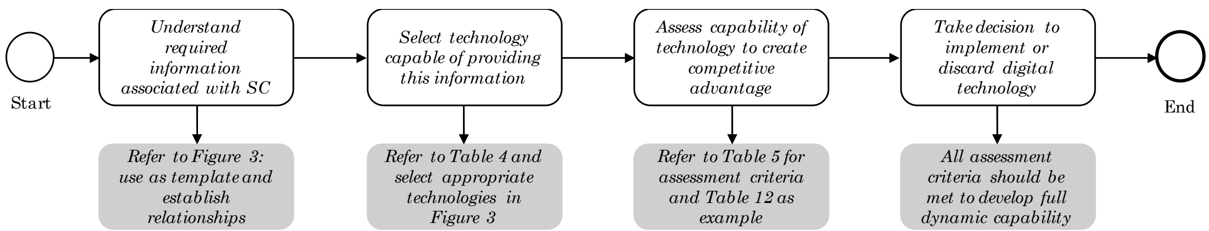

Figure 6:Digital technology selection from a dynamic capabilities perspective

6.1 Key findings

The key findings are presented in Table 10.

Key findings	**Implication**
1. Digitalisation	
"Digital supply chains can be described as the interconnectedness between cyber-physical systems capable of storing, processing, providing and vertically and horizontally exchanging information	Common understanding of digital supply chains amongst academia and industry.

along the entire supply chain in real-time through enabling digital technologies."	
4 key technologies are required for supply chain digitalisation: Big Data Analytics, Track & Trace, Social Media, MES & ERP	Clarity about required digital technologies for digitalisation of supply chains.
2. Decision-making in supply chains	
Allocation of information to particular supply chain decisions, required technology to capture this information and source of the information.	Improvement of supply chain decision-making and company performance by having required information available.
3. Dynamic Capabilities	
In general, single digital technologies do not fulfil all criteria to qualify as dynamic capabilities. To reap the full competitive advantage, digital technologies need to be used jointly.	Development of understanding about required digital technologies for decision-making required. → The framework "Digital technology selection from a dynamic capabilities perspective" developed in this research supports this.

Table 10: Key findings and their implication

Further findings and their implication are presented in Table 11.

Further findings	**Implication**
1. Digitalisation	
The understanding of digital technologies might differ according to context, for example: Cyber-physical systems can be only a production machine, such as CNC machine but also the entire supply chain as an integration of various technologies	Requirement to clarify context prior to identification of appropriate technology for desired outcome.
2 different classifications were developed: a) according to characteristics b) according to application	a) Similar technologies are grouped and present guidance for available technologies within clusters. b) Description of application of technology to provide guidance for users.
2. Decision-making in supply chains	
All information identified is required for strategic, tactical and operational decision-making	Establishment of data base comprising of internal and external information to which managers on <u>all levels</u> have access required.
The digital technologies proposed capture company internal and external information identified and required for supply chain decision-making	Decision-making is based on high quality information, which would otherwise a) not be available, b) lack quality, c) lead to decision-making based on unreliable assumptions.

To deliver all information required for decision-making, digital technologies must be integrated. Otherwise information might be missing	Establishment of data integration platforms to gather all information captured by various digital technologies required.

Table 11: Further findings and their implication

6.2 Limitations of Research & Further Research

This research has a few limitations. First, 14 interviews were conducted to identify how digital technologies in supply chains can be a source of competitive advantage. Hence, this research can be seen as preliminary answer; however, it is recommended to extend the research to a larger pool of interview participants.

Secondly, the research focused on required information for decision-making from the perspective of the manufacturing firm as focal company in the supply chain. However, digitalisation requires commitment of all supply chain partners and not all supply chain partners might have the resources to digitalise. Hence it would be interesting to investigate the readiness for digitalisation in the upstream and downstream supply network from a complex adaptive systems perspective.

6.3 Theoretical Contributions

This research has several theoretical contributions, which are presented in Table 12.

Theoretical Contributions		
Topic	*Tools created*	*Status*
1. Digitalisation		
Definition of Digital Supply Chains		Modified
Classification of digital technologies		Established (from literature review)
Motives for digitalisation		Established
Barriers for digitalisation		Established
2. Relationships in supply chain decision-making		
Decision-Information	Design-Structure Matrix	Established
Information-Source	Design-Structure-Matrix	Established
Information-Digital Technology	Design-Structure-Matrix	Established
Decision-Information-Source-Digital Technology	Design-Structure-Matrix	Established
3. Digital Technologies in the context of dynamic capabilities		

Qualification of identified digital technologies as dynamic capabilities and impact		Established
Qualification of general digital technologies as dynamic capabilities	Dynamic Capabilities Assessment Framework	Established

Table 12: Theoretical Contributions

6.4 Practical Contributions

This research informs companies what information they require for particular supply chain decisions to be able to make well-informed decisions. This can significantly improve decision-making in terms of appropriateness and velocity, which can improve company performance. Secondly, the research brings clarity to companies what identified digital technologies are best suitable for digitalising a supply chain. This work also informs companies how digital technologies can create competitive advantage. A "Dynamic Capability Qualification Framework" was suggested that helps companies identify whether particular technologies, that might not have been considered in the research, can be a source of competitive advantage.

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Towards the development of cyber-resilient supply chains

How to identify and mitigate cyber-risks in the context of digital supply chains

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Abstract

The ever-increasing reliance of businesses on digital technologies to improve supply-chain performance exacerbates a firm's exposure to the risk of cyber-attacks. However, existing supply-chain-risk-management frameworks lack to incorporate the phenomenon of cyber-risk. To address this gap, this paper seeks to develop a conceptual cyber-resilience framework for digital supply chains incorporating cyber-vulnerabilities, risks and mitigation strategies. Extant literature in supply chain, risk management, digital technologies and cyber-risks was reviewed to develop a conceptual framework guiding the data-collection. Nine interviews with experts representing vital stakeholder-groups of cyber-security-organisations were carried out, forming together an explorative case-study. This data was analysed to capture key cyber-vulnerabilities, cyber-risks and mitigation strategies of digital technologies facilitating supply chain activities. Based on the findings, a cyber-resilience framework involving 19 steps is proposed. This novel approach facilitates the identification and mitigation of cyber-risks in digital supply chains. The case studies conducted comprised of cyber-security-organisations associated with highly digitalised companies from the automotive, pharmaceutical and electronic industries operating in Germany. To increase generalisability of this study, additional case studies with firms from other industries and countries are suggested. Moreover, the proposed framework would require further testing to ensure its validity. This paper captures the relation between digital technologies and cyber-risks embedded in a supply-chain environment. In encapsulating these linkages into a holistic cyber-resilience framework, it establishes a common ground among disciplines formerly dispersed.

Keywords: Cyber-resilience, cyber-supply-chain-risks, digital supply chain risks, cyber security in supply chains,

Introduction

Since the 2000s, activities carried out in supply chains are being increasingly facilitated by digital technologies such as data analytics, cloud-computing and RFID. By employing these powerful resources, traditional supply chains are transforming to what industrialist's coin as '*digital-supply-chains*'. Value adding can arise from horizontal integration through value networks, end-to-end digital integration of processes and full vertical transparency within companies (Kargermann et al. 2013). A study conducted by The Boston Consulting Group (2016) demonstrates that firms engaging in digital supply chains benefit from an increase of product availability of 10 percentage points, 25% faster response times to demand-changes, and 30% improvement on realisations of working-capital reductions.

However, as much as these developments provide ample opportunities to businesses, the challenges accompanying this shift are not negligible. An ever-increasing interconnection of entities within companies and across the entire supply chain as well as intensified complexity of processes increases a company's exposure to potential threats (Khan & Estay 2015). Since information technology will be an integral part of businesses in the future, its inherent threats will be replicated onto the entire supply chain. In other words, digital supply chain driven enterprises will be more highly exposed and susceptible to threats of cyber-attack (Choo 2011).

Systematic literature review revealed that no supply chain risk framework exists, which incorporates the phenomenon of cyber-risk. Firstly, numerous papers were published with regards to security concerns of big data analytics (Bertino 2015; Perera et al. 2015; Matturdi et al. 2014), cloud computing (Liu et al. 2013; Grobauer et al. 2011) and cyber-physical systems (Vollmer & Manic 2014; Pasqualetti et al. 2013; Sridhar et al. 2012). However, these risks were not linked with the effect they could have on supply chain risks. Secondly, the review of the literature revealed that only one paper was identified to cover the topic of cyber-resilience in supply chains: Boyes (2015) proposed a framework for cyber security attributes of assets within a supply chain. In doing so, he missed to connect particular digital technologies with supply chain activities and therefore, could not study the full scale of cyber risks in the context of supply chains. Finally, Khan & Estay (2015) conducted a systematic literature review on articles covering cyber resilience of supply chains and found that among the 213 analysed publications not a single paper studied or developed a framework to address cyber security in digital supply chains.

With respect to these gaps, it was concluded that there is no publicly available, English written paper addressing the question as to what cyber risks a supply chain is exposed to when deploying digital technologies, let alone mitigation strategies to cope with these. Gaining these insights would provide great value to companies embedded in vibrant and turbulent environments. Based on these findings, this paper aims to explore the following research question:

'How to identify and mitigate cyber-risks in digital supply chains?'

To support and complement the above question, this paper also aims at answering the following key questions:

- What are the vulnerabilities of digital technologies applied to facilitate supply chain and factory level activities?
- What are the cyber-risks associated with these?
- How can these risks be mitigated?

Theoretical background

Strategic, tactical and operational supply chain activities

SC research distinguishes between strategic (Bolstorflf & Rosenbaum 2004 & Chandra & Grabis 2007) and tactical/operational (Lambert et al. 1998 & Graves & Willems 2003) supply chain activities. According to Xu et al. (2000), these activities require a set of information, gathered either from the supplier's-, the focal company's- or the customer's business functions. Furthermore, information collected from third-party companies (Market research company, distribution service providers etc.) also need to be considered (Graves & Willems 2003). An integration of the above mentioned components is required to understand the scope of SC activities. The framework presented in *Figure 1* is suggested to integrate SC activities, information required and business functions involved (across firm boundaries).

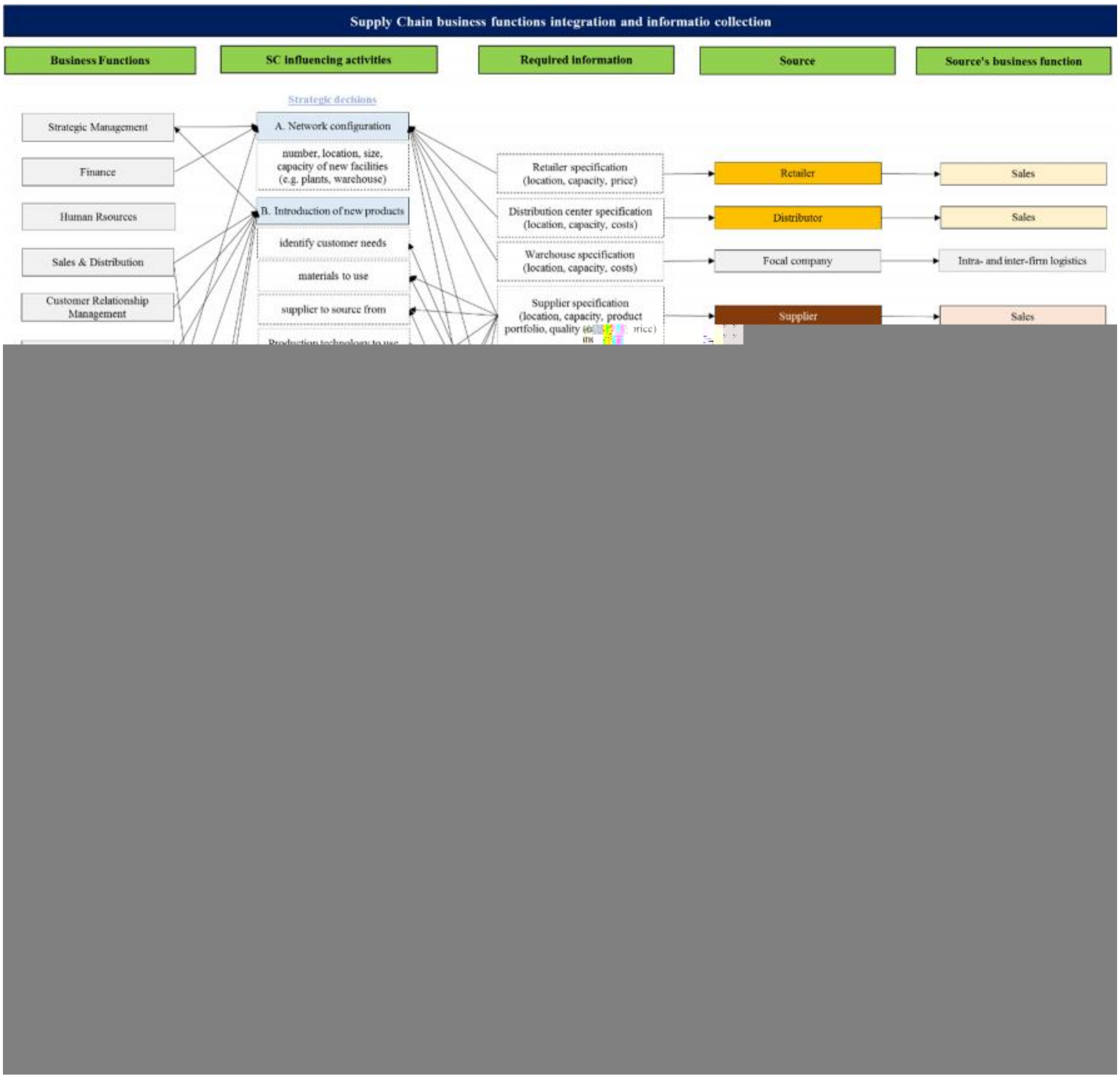

Figure 1: Cross-firm information flow for supply chain activities

The framework above (developed from Chandra & Grabis 2007; Lambert et al. 1998; Bolstorflf & Rosenbaum 2004) indicates that SC activities require information. This information is captured from various sources (within & outside firm) and their business functions. However, the SC-activities depicted in *Figure 1* have inherent risks, which need to be addressed.

Supply chain risks

Kumar & Gregory (2013) identified that the meaning of risk is twofold in the academic literature: Risks could be related to events with both negative and positive consequences, or, risks could be associated with only negative consequences. The former is rooted in disciplines such as decision-making and financial theories, the latter is linked to risks triggered by, for example, supply chain disruptions (March & Shapira 1987).

Wagner & Neshat (2010) state that a supply chain risk is a *'(…) negative deviation from the expected value of a performance measure resulting in negative consequences for the focal firm'*; and performance measures could be, for example, quality, time, cost, sustainability-conformance etc. (Beamon 1999). Manuj & Mentzer (2008) analysed risk in a more detailed manner and distinguished between supply-, operational- as well as demand-risks, which leads to the fairly fragmented concept in supply chain risk literature: risk-classification.

Various risk-classification attempts can be combined and regrouped together to illustrate an exhaustive list of supply-chain risks. *Figure 2* presents this overarching classification of risks.

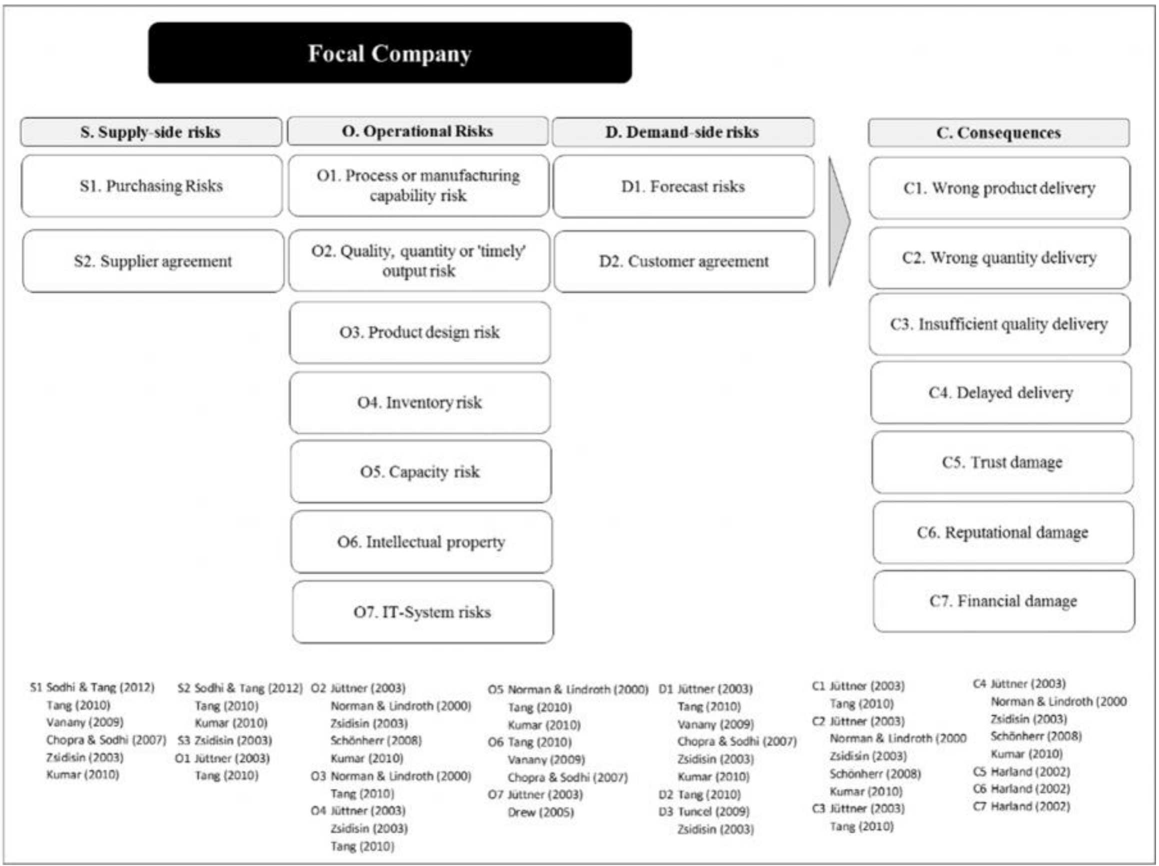

Figure 2: Risk classification combined from various authors

However, review of the literature has not pointed to any framework analysing the relation between different risk types among supply chain nodes. ***Error! Reference source not found.*** - ***Error! Reference source not found.*** depict exactly these inter-relationships of risk types among suppliers, the focal company, distributors and customers.

			Tier-1 Supplier																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Tier-1 Supplier: Supply-side	Purchasing risks	S1			*	*	*	*		*				*	*	*	*	*	*	*
Tier-1 Supplier: Supply-side	Supplier agreement	S2	*			*				*	*			*	*	*	*			*
Tier-1 Supplier: Operational risks	Process / manuf. capab. Risks	O1				*			*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Quality, quantity, timely output risks	O2						*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Product design risk	O3	*	*		*				*				*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Inventory risk	O4				*			*			*		*	*		*	*	*	*
Tier-1 Supplier: Operational risks	Capacity risk	O5				*		*				*		*	*		*	*	*	*
Tier-1 Supplier: Operational risks	Intellectual property risk	O6		*			*						*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Forecast risks	D1	*			*	*	*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Customer agreement risk	D2				*	*			*	*	*		*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Product delivery risks	C1															*	*	*	*
Tier-1 Supplier: Consequences	Quantity risks	C2															*	*	*	*
Tier-1 Supplier: Consequences	Quality risks	C3															*	*	*	*
Tier-1 Supplier: Consequences	Delay risks	C4																*	*	*
Tier-1 Supplier: Consequences	Trust risks	C5																	*	*
Tier-1 Supplier: Consequences	Reputational risks	C6																		*
Tier-1 Supplier: Consequences	Financial risks	C7																		*

			Focal Company																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Tier-1 Supplier: Supply-side	Purchasing risks	S1				*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Supply-side	Supplier agreement	S2				*		*		*				*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Process / manuf. capab. Risks	O1				*	*	*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Quality, quantity, timely output risks	O2			*	*		*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Product design risk	O3		*	*	*	*	*	*	*				*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Inventory risk	O4				*		*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Capacity risk	O5				*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Intellectual property risk	O6		*		*	*			*				*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	IT-System risks	O7	*	*		*	*	*		*	*			*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Forecast risks	D1	*			*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Customer agreement risk	D2		*		*	*	*		*				*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Product delivery risks	C1	*	*		*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Quantity risks	C2	*	*		*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Quality risks	C3	*	*	*	*								*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Delay risks	C4	*	*		*		*						*	*		*	*	*	*
Tier-1 Supplier: Consequences	Trust risks	C5		*				*	*	*								*	*	*
Tier-1 Supplier: Consequences	Reputational risks	C6																*	*	*
Tier-1 Supplier: Consequences	Financial risks	C7	*	*		*		*	*	*	*			*	*	*	*	*	*	*

			Distributor													
			Supply- and operational risks					Demand-side risks		Consequences/Impact						
			Supplier agreement	Quantity or 'timely' output risk	Inventory risk	Capacity risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S2	O2	O4	O5	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Tier-1 Supplier: Supply-side	Purchasing risks	S1		*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Supply-side	Supplier agreement	S2		*							*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Process / manuf. capab. Risks	O1		*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Quality, quantity, timely output risks	O2		*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Product design risk	O3	*	*					*	*		*	*	*	*	*
Tier-1 Supplier: Operational risks	Inventory risk	O4		*	*				*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Capacity risk	O5	*	*	*				*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Intellectual property risk	O6	*						*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Forecast risks	D1		*	*	*			*	*	*		*	*	*	*
Tier-1 Supplier: Demand side	Customer agreement risk	D2	*	*	*				*	*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Product delivery risks	C1	*	*	*				*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Quantity risks	C2	*	*	*				*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Quality risks	C3	*							*		*	*	*	*	*
Tier-1 Supplier: Consequences	Delay risks	C4	*	*	*				*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Trust risks	C5		*	*	*				*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Reputational risks	C6			*	*				*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Financial risks	C7	*	*	*	*	*		*	*	*	*	*	*	*	*

			Tier-1 Customer																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Tier-1 Supplier: Supply-side	Purchasing risks	S1			*	*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Supply-side	Supplier agreement	S2				*								*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Process / manuf. capab. Risks	O1				*	*	*	*					*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Quality, quantity, timely output risks	O2	*		*	*		*						*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Product design risk	O3	*			*	*						*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Inventory risk	O4		*	*	*		*					*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Capacity risk	O5	*	*	*	*		*					*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	Intellectual property risk	O6	*	*		*	*			*			*	*	*	*	*	*	*	*
Tier-1 Supplier: Operational risks	IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tier-1 Supplier: Demand side	Forecast risks	D1	*			*		*					*	*	*		*	*	*	*
Tier-1 Supplier: Demand side	Customer agreement risk	D2	*	*	*	*	*	*		*				*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Product delivery risks	C1		*		*		*					*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Quantity risks	C2		*		*		*					*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Quality risks	C3		*	*	*		*					*	*		*	*	*	*	*
Tier-1 Supplier: Consequences	Delay risks	C4		*		*		*					*	*	*		*	*	*	*
Tier-1 Supplier: Consequences	Trust risks	C5		*				*	*	*			*	*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Reputational risks	C6		*		*		*	*	*			*	*	*	*	*	*	*	*
Tier-1 Supplier: Consequences	Financial risks	C7		*		*		*	*	*		*	*	*	*	*	*	*	*	*

Figure 3: Impact of supply chain risks triggered by supplier on supply chain

				Tier-1 Supplier																	
				Supply-side		Operational Risks							Demand-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Focal Company	Supply-	Purchasing risks	S1																		
		Supplier agreement	S2																		
	Operational risks	Process / manuf. capab. Risks	O1																		
		Quality, quantity, timely output risks	O2																		
		Product design risk	O3																		
		Inventory risk	O4																		
		Capacity risk	O5																		
		Intellectual property risk	O6																		
		IT-System risks	O7																		
	Demand side	Forecast risks	D1																		
		Customer agreement risk	D2																		
	Consequences	Product delivery risks	C1																		
		Quantity risks	C2																		
		Quality risks	C3																		
		Delay risks	C4																		
		Trust risks	C5																		
		Reputational risks	C6																		
		Financial risks	C7																		

				Focal Company																	
				Supply-side		Operational Risks							Demand-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Focal Company	Supply-	Purchasing risks	S1			*	*	*	*		*				*	*	*	*	*	*	*
		Supplier agreement	S2	*			*				*	*			*	*	*	*			*
	Operational risks	Process / manuf. capab. Risks	O1				*			*					*	*	*	*	*	*	*
		Quality, quantity, timely output risks	O2						*	*					*	*	*	*	*	*	*
		Product design risk	O3	*	*		*				*				*	*	*	*	*	*	*
		Inventory risk	O4				*			*			*		*	*		*	*	*	*
		Capacity risk	O5				*		*				*		*	*		*	*	*	*
		Intellectual property risk	O6		*			*						*	*	*	*	*	*	*	*
		IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Demand side	Forecast risks	D1	*			*	*	*	*					*	*	*	*	*	*	*
		Customer agreement risk	D2				*	*			*	*	*		*	*	*	*	*	*	*
	Consequences	Product delivery risks	C1															*	*	*	*
		Quantity risks	C2															*	*	*	*
		Quality risks	C3															*	*	*	*
		Delay risks	C4																*	*	*
		Trust risks	C5																	*	*
		Reputational risks	C6																		*
		Financial risks	C7																		*

				Distributor													
				Supply- and operational risks					Demand-side risks		Consequences/Impact						
				Supplier agreement	Quantity or 'timely' output risk	Inventory risk	Capacity risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S2	O2	O4	O5	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Focal Company	Supply-	Purchasing risks	S1		*	*					*	*	*	*	*	*	*
		Supplier agreement	S2		*	*					*	*	*	*	*	*	*
	Operational risks	Process / manuf. capab. Risks	O1		*	*	*				*	*	*	*	*	*	*
		Quality, quantity, timely output risks	O2		*	*	*				*	*	*	*	*	*	*
		Product design risk	O3	*	*	*	*				*	*	*	*	*	*	*
		Inventory risk	O4		*	*	*				*	*	*	*	*	*	*
		Capacity risk	O5		*	*					*	*	*	*	*	*	*
		Intellectual property risk	O6	*	*						*	*	*	*	*	*	*
		IT-System risks	O7	*	*	*		*			*	*	*	*	*	*	*
	Demand side	Forecast risks	D1		*	*					*	*	*	*	*	*	*
		Customer agreement risk	D2	*	*	*					*	*	*	*	*	*	*
	Consequences	Product delivery risks	C1	*	*	*					*	*	*	*	*	*	*
		Quantity risks	C2	*	*	*					*	*	*	*	*	*	*
		Quality risks	C3	*	*						*	*	*	*	*	*	*
		Delay risks	C4	*	*	*					*	*		*	*	*	*
		Trust risks	C5	*		*	*								*	*	*
		Reputational risks	C6												*	*	*
		Financial risks	C7								*	*	*	*	*	*	*

				Tier-1 Customer																	
				Supply-side		Operational Risks							Demand-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Focal Company	Supply-	Purchasing risks	S1		*		*		*	*	*	*		*	*	*	*	*	*	*	*
		Supplier agreement	S2				*		*						*	*	*	*	*	*	*
	Operational risks	Process / manuf. capab. Risks	O1				*		*		*				*	*	*	*	*	*	*
		Quality, quantity, timely output risks	O2				*	*	*	*					*	*	*	*	*	*	*
		Product design risk	O3			*	*		*	*					*	*	*	*	*	*	*
		Inventory risk	O4		*	*	*	*	*	*	*				*	*	*	*	*	*	*
		Capacity risk	O5				*		*	*					*	*	*	*	*	*	*
		Intellectual property risk	O6				*		*						*	*	*	*	*	*	*
		IT-System risks	O7		*		*	*			*				*	*	*	*	*	*	*
	Demand side	Forecast risks	D1	*	*		*	*	*		*	*			*	*	*	*	*	*	*
		Customer agreement risk	D2	*			*		*						*	*	*	*	*	*	*
	Consequences	Product delivery risks	C1		*		*	*	*		*				*	*	*	*	*	*	*
		Quantity risks	C2	*	*		*		*						*	*	*	*	*	*	*
		Quality risks	C3	*	*		*		*						*	*	*	*	*	*	*
		Delay risks	C4	*	*	*	*								*	*	*	*	*	*	*
		Trust risks	C5	*	*		*		*						*	*		*	*	*	*
		Reputational risks	C6		*				*	*	*								*	*	*
		Financial risks	C7																*	*	*

Figure 4: Impact of supply chain risks triggered by focal company on supply chain

				Tier-1 Supplier																	
				Supply-side		Operational Risks							Demand-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Distributor	Supply- and operational	Supplier agreement	S2																		
		Quantity and 'timely' output risks	O2																		
		Inventory risk	O4																		
		Capacity risk	O5																		
		IT-System risks	O7																		
	Deman d side	Forecast risks	D1																		
		Customer agreement risk	D2																		
	Consequences	Product delivery risks	C1																		
		Quantity risks	C2																		
		Quality risks	C3																		
		Delay risks	C4																		
		Trust risks	C5																		
		Reputational risks	C6																		
		Financial risks	C7																		

				Focal Company																	
				Supply-side		Operational Risks							Demand-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Distributor	Supply- and operational	Supplier agreement	S2																		
		Quantity and 'timely' output risks	O2																		
		Inventory risk	O4																		
		Capacity risk	O5																		
		IT-System risks	O7																		
	Deman d side	Forecast risks	D1																		
		Customer agreement risk	D2																		
	Consequences	Product delivery risks	C1																		
		Quantity risks	C2																		
		Quality risks	C3																		
		Delay risks	C4																		
		Trust risks	C5																		
		Reputational risks	C6																		
		Financial risks	C7																		

				Distributor													
				Supply- and operational risks					Demand-side risks		Consequences/Impact						
				Supplier agreement	Quantity or 'timely' output risk	Inventory risk	Capacity risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S2	O2	O4	O5	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Distributor	Supply- and operational	Supplier agreement	S2		*			*			*	*	*	*			*
		Quantity and 'timely' output risks	O2			*	*				*	*	*	*	*	*	*
		Inventory risk	O4		*		*		*		*	*		*	*	*	*
		Capacity risk	O5		*	*			*		*	*		*	*	*	*
		IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Deman d side	Forecast risks	D1		*	*	*				*	*	*	*	*	*	*
		Customer agreement risk	D2		*			*	*		*	*	*	*	*	*	*
	Consequences	Product delivery risks	C1											*	*	*	*
		Quantity risks	C2											*	*	*	*
		Quality risks	C3											*	*	*	*
		Delay risks	C4												*	*	*
		Trust risks	C5													*	*
		Reputational risks	C6														*
		Financial risks	C7														*

				Tier-1 Customer																	
				Supply-side		Operational Risks							Deman d-side		Consequences/Impact						
				Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
				S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Distributor	Supply- and operational	Supplier agreement	S2	*	*		*		*	*	*	*			*	*	*	*	*	*	*
		Quantity and 'timely' output risks	O2			*	*		*	*					*	*	*	*	*	*	*
		Inventory risk	O4				*		*	*					*	*	*	*	*	*	*
		Capacity risk	O5				*		*						*	*	*	*	*	*	*
		IT-System risks	O7	*	*		*	*	*		*	*			*	*	*	*	*	*	*
	Deman d side	Forecast risks	D1	*			*		*						*	*	*	*	*	*	*
		Customer agreement risk	D2		*		*	*	*		*				*	*	*	*	*	*	*
	Consequences	Product delivery risks	C1	*	*		*		*						*	*	*	*	*	*	*
		Quantity risks	C2	*	*		*		*						*	*	*	*	*	*	*
		Quality risks	C3	*	*	*	*								*	*	*	*	*	*	*
		Delay risks	C4	*	*		*		*						*	*		*	*	*	*
		Trust risks	C5		*				*	*	*								*	*	*
		Reputational risks	C6																*	*	*
		Financial risks	C7												*	*	*	*	*	*	*

Figure 5: Impact of supply chain risks triggered by distributor on supply chain

Tier-1 Customer			Tier-1 Supplier																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Supply-	Purchasing risks	S1																		
	Supplier agreement	S2																		
Operational risks	Process / manuf. capab. Risks	O1																		
	Quality, quantity, timely output risks	O2																		
	Product design risk	O3																		
	Inventory risk	O4																		
	Capacity risk	O5																		
	Intellectual property risk	O6																		
	IT-System risks	O7																		
Demand-side	Forecast risks	D1																		
	Customer agreement risk	D2																		
Consequences	Product delivery risks	C1																		
	Quantity risks	C2																		
	Quality risks	C3																		
	Delay risks	C4																		
	Trust risks	C5																		
	Reputational risks	C6																		
	Financial risks	C7																		

Tier-1 Customer			Focal Company																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Supply-	Purchasing risks	S1																		
	Supplier agreement	S2																		
Operational risks	Process / manuf. capab. Risks	O1																		
	Quality, quantity, timely output risks	O2																		
	Product design risk	O3																		
	Inventory risk	O4																		
	Capacity risk	O5																		
	Intellectual property risk	O6																		
	IT-System risks	O7																		
Demand-side	Forecast risks	D1																		
	Customer agreement risk	D2																		
Consequences	Product delivery risks	C1																		
	Quantity risks	C2																		
	Quality risks	C3																		
	Delay risks	C4																		
	Trust risks	C5																		
	Reputational risks	C6																		
	Financial risks	C7																		

Tier-1 Customer			Distributor													
			Supply- and operational risks					Demand-side risks		Consequences/Impact						
			Supplier agreement	Quantity or 'timely' output risk	Inventory risk	Capacity risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S2	O2	O4	O5	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Supply-	Purchasing risks	S1														
	Supplier agreement	S2														
Operational risks	Process / manuf. capab. Risks	O1														
	Quality, quantity, timely output risks	O2														
	Product design risk	O3														
	Inventory risk	O4														
	Capacity risk	O5														
	Intellectual property risk	O6														
	IT-System risks	O7														
Demand-side	Forecast risks	D1														
	Customer agreement risk	D2														
Consequences	Product delivery risks	C1														
	Quantity risks	C2														
	Quality risks	C3														
	Delay risks	C4														
	Trust risks	C5														
	Reputational risks	C6														
	Financial risks	C7														

Tier-1 Customer			Tier-1 Customer																	
			Supply-side		Operational Risks							Demand-side		Consequences/Impact						
			Purchasing risks	Supplier agreement	Process or manufacturing capability risk	Quality, quantity, or 'timely' output risk	Product design risk	Inventory risk	Capacity risk	Intellectual property risk	IT-System risks	Forecast risks	Customer agreement	Product delivery risk	Quantity risk	Quality risk	Delay risk	Trust risks	Reputational risks	Financial risks
			S1	S2	O1	O2	O3	O4	O5	O6	O7	D1	D2	C1	C2	C3	C4	C5	C6	C7
Supply-	Purchasing risks	S1			*	*	*	*		*				*	*	*	*	*	*	*
	Supplier agreement	S2	*			*				*	*			*	*	*	*			*
Operational risks	Process / manuf. capab. Risks	O1				*			*					*	*	*	*	*	*	*
	Quality, quantity, timely output risks	O2						*	*					*	*	*	*	*	*	*
	Product design risk	O3	*	*		*				*				*	*	*	*	*	*	*
	Inventory risk	O4				*			*			*		*	*		*	*	*	*
	Capacity risk	O5				*		*				*		*	*		*	*	*	*
	Intellectual property risk	O6		*			*						*	*	*	*	*	*	*	*
	IT-System risks	O7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Demand-side	Forecast risks	D1	*			*	*	*	*					*	*	*	*	*	*	*
	Customer agreement risk	D2				*	*			*	*	*		*	*	*	*	*	*	*
Consequences	Product delivery risks	C1															*	*	*	*
	Quantity risks	C2															*	*	*	*
	Quality risks	C3															*	*	*	*
	Delay risks	C4																*	*	*
	Trust risks	C5																	*	*
	Reputational risks	C6																		*
	Financial risks	C7																		*

Figure 6: SC-risks triggered by customer on customer itself

To increase a firm's ability to withstand impact of supply-chain-risks, researchers attempted to develop supply chain risk management frameworks.

Supply chain risk management frameworks

In addition to the unit of analysis, the literature of supply-chain-risk-management was fragmented due to the applied rigor when analysing risks and suggesting mitigation strategies.

Among the frameworks reviewed, the approach developed by Kumar (2015) was deemed fit for this paper. It is designed in an exhaustive manner as it incorporates all relevant risk-associated aspects. Also, the framework appears well-structured using the supply chain configuration to identify and mitigate supply chain risks. *Figure 7* illustrates the framework:

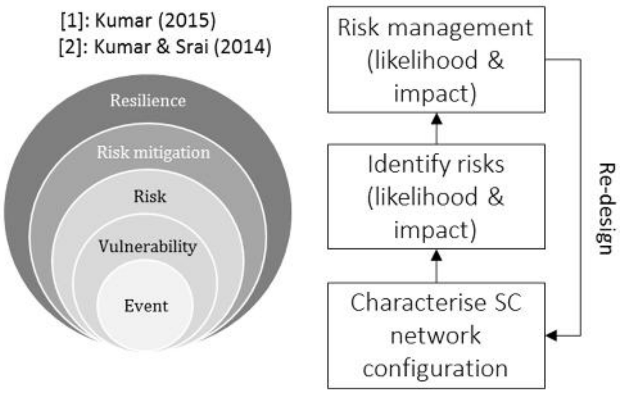

Figure 7: Supply chain risk management framework (Kumar 2015; Kumar & Srai 2014)

To facilitate activities carried out in a supply chain, digital technologies are applied.

Digital technologies in supply chains

The literature was reviewed for the definition of 'digital supply chain'(DSC). The six DSC related definitions found[1] were different in the unit of analysis as well as the benefits enabled for the supply chains through DT. Combining all partly relevant depictions of the term together led to the following definition: '*A set of multiple, globally dispersed organisation using digital technologies to decouple the physical proximity of material flow and coordination, increase the supply chain visibility, and leverage decision making processes such that the customer is provided with a faster delivery, increased quality and/or lower cost of products/services'* (Verdouw et al. 2016; Bhargava et al. 2013; Giménez & Lourenço 2008; J. T. Mentzer et al. 2001). Review of the fairly fragmented knowledge body revealed that DTs generally can be classified as (a) technologies used for both supply chain activities and shop floor activities as well as (b) digital technologies specifically dedicated for shop floor operations.

1. *Real-time-locating-systems (RTLS)*

Various definitions of the term RTLS (Li et al. 2016; Boulos & Berry) were analysed. Boulos & Berry (2012) argue that RTLS are *'systems for the identification and tracking of the location of assets and/or persons in real or near-real time'*. The main differences among RTLS-technologies arise from the range to track (objects within facility or across supply chain), the accuracy and the time needed to transmit the data (frequency). Literature suggests that implementing RTLS-technologies increases the supply chain visibility, enables track and trace of products along the entire supply chain, streamline inventory management processes and support after sales services.

2. *Cloud Computing*

Mell & Grance (2011) argue that *'cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources, that can be rapidly provisioned and released with minimal management effort or service provider interaction'*. The review of 'cloud computing' literature shows that cloud computing can be offered through different service types: software-as-a-service, platform-as-a-service as and infrastructure-as-a-service. Literature suggests that utilising cloud-resources enables firms to benefit from a rapid deployment, scalable infrastructure and low upfront investment in cyber-resources.

3. *(Small) and big data analytics*

Review of the literature revealed that a general consensus among academics exists as to what the main characteristics of big data are: high variety (various sources of information generation), high volume, high velocity (pace of data generation and transmission), high value (business value) and high veracity ('messiness of data') of data (5Vs). The latter is often referred to as 'unstructured' data and shapes the striking difference between big and small data (small data are usually laid out in a structured fashion). This large amount of data requires systematic analysis, which is coined by many researchers (Leveling et al. 2014; Wamba & Akter 2015; Chen et al. 2015) as *'big data analytics'* (Wamba & Akter 2015). Process steps within big data analytics include: (1) collecting data from various internal and external data sources, (2) 'cleaning' information according to the specific use case, (3) integrating information from various sources to prepare analytics and lastly, (4) applying intelligence to provide in-depth insight (*see* ***Error! Reference source not found.*** *for sources*). This process can be applied to a variety of use cases in supply chains, which are categorised into *'sourcing'*, *'making'*, *'moving'* as well as *'selling'* (*see* ***Error! Reference source not found.*** *for sources*). In employing big data analytics, literature suggests that new, broad, accurate and in-depth insight into various business fields can be gained. Thus, enabling firms to achieve competitive advantage (Fang et al. 2015).

4. *Platforms and Enterprise Business Systems (EBS)*

The integration of vital business functions in a firm requires applications for information generation, processing and exchange (Bendoly et al. 2006). Core capabilities of these systems are the integration of information from finance, procurement, operations, sales & marketing or logistics within (EBS) and across firms (platforms) (Huang & Handfield 2015). Literature suggests that implementing these information systems enables firms to increase the visibility across the supply chain, manage uncertainty and increase productivity significantly.

In addition to the DT mentioned above, some technologies are specifically dedicated for the application on shop-floor level.

5. *Cyber-physical systems (CPS)*

CPS referred to as core enabler for future digital manufacturing as they are bringing together technology concepts of embedded systems, sensors (e.g. RFID), manufacturing intelligence (e.g. big data analytics), communication interfaces to other systems (e.g. M2M communication, cloud computing) or advanced human-machine interfaces (e.g. augmented reality)(Geisberger et al. 2011). Characteristics of CPMS are to record the physical environment, process these data in collaboration with the digital world and manipulate physical objects using actuators (Geisberger et al. 2011). Literature suggests that implementation of CPS optimises production processes, increase resource efficiency and enable mass customisation (Geisberger et al. 2011).

To gain a thorough understanding how these technologies could improve supply chain performance, they need to be linked with the key supply chain activities. These linkages are presented in *Table 1* and *Table 2.*

Onion framework

The conceptualisation of the contextual application of digital technologies across supply chain and factory levels is depicted in Figure 8. Strategic activities are supported by 2 layers, tactical/operational activities by 3 layers and shop-floor levels by 4 layers of digital technology groups.

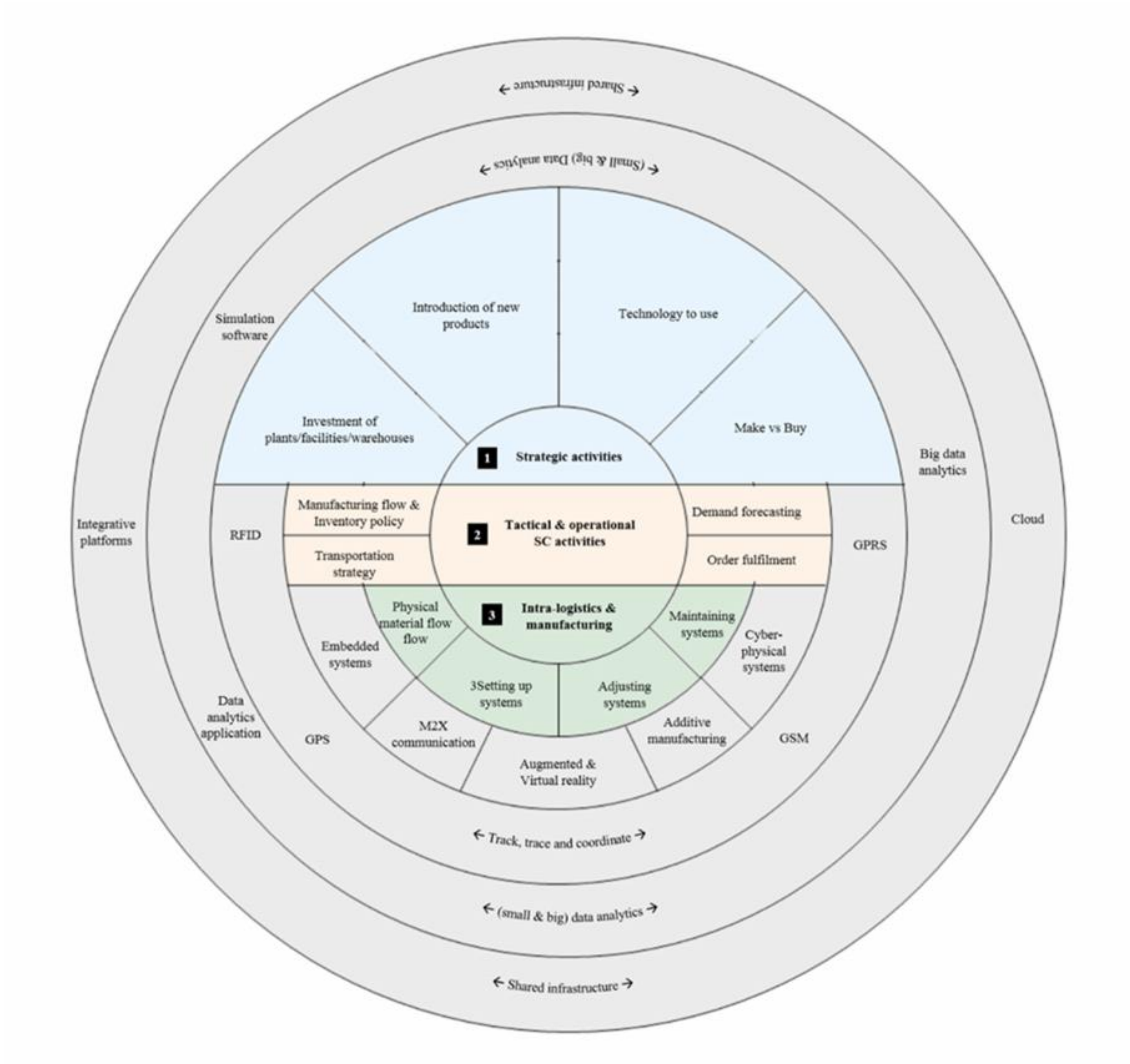

Figure 8: Onion framework - contextual application of digital technologies

However, these technologies have inherent cyber-risks, which need to be addressed.

Table 1: SCM activities and digital technologies from literature (I)

	Supply Chain node affected and cross-supply chain information flow																					
	Supplier					**Focal Company**					**Distributor**					**Customer**					**Public Domain**	**Digital Technologies usable from literature**
	Procurement	*Capacity/ planning &control*	*Manuf. & Logistics*	*Sales and after sales*	*Management & Finance*	*Procurement*	*Capacity planning & control*	*Manufact. & Logistics*	*Sales & Marketing*	*Management & Fiance*	*Procurement*	*Capacity planning & control*	*Logistics*	*Sales and after Sales*	*Management & Finance*	*Procurement*	*Capacity planning & control*	*Manufac. & Logistics*	*Sales & after Sales*	*Management & Finance*		
A. Strategic activities	***Information required from each supply chain node and business function affected***																					
Network configuration (Investment on new supply chain nodes (plants, warehouses etc.) and supply chain arches (distribution channels))				Supplier facility		Current supplier base	Existing and needed capacity	Transportation requirements	Customer base/ Demand	Budget			Feasibility/ Distrib. Prices			Customer facility					• Geographical and infrastructure conditions • Tax regulations • Competitive landscape	Big Data analytics (Ping L.a Liu 2011; Sanders 2016) Platforms (Rai et al. 2006)
Production technology to implement				Technology product		Technology supplier base	Current and future	Requirement s		Budget						Requirement s					• Technology trends	Platforms (Rai et al. 2006)
Introduction of new products				Prices for raw materials		Supplier specification	Current & future capacity	Capabilities	Market trends	Budget & Strategy	Distrib. Channel to new market		Distrib. Channel to new market			Feedback & needs					• Customer needs, trends, social media activities	Big Data analytics (Sagiroglu & Sinanc 2013; Ping L.a Liu 2011) Platforms (Rai et al. 2006)
Makes vs Buy				Prices for components		Supplier base and specification	Current & future capacity	Production costs		Cost for manning level etc.						Quality, quantity, price requirement					•	Big Data Analytics (Sanders 2016) Platforms (Rai et al. 2006)

Table 2: SCM activities and digital technologies from literature (II)

	Supplier					**Focal Company**					**Distributor**					**Customer**					**Public Domain**	
	Procurement	*Capacity/ planning &control*	*Logistics*	*Sales and after sales*	*Management & Finance*	*Procurement*	*Capacity planning & control*	*Manufact. & Logistics*	*Sales & Marketing*	*Management & Fiance*	*Procurement*	*Capacity planning & control*	*Logistics*	*Sales and after Sales*	*Management & Finance*	*Procurement*	*Capacity planning & control*	*Manufac. & Logistics*	*Sales & after Sales*	*Management & Finance*		**Digital Technologies usable from literature**
B. Tactical activities																						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Big Data Analytics (Sanders 2016) Cloud computing (Srivastava 2013) [illegible]

<u>Cyber attack</u>

Three different types of cyber-attacks exist: (1) Exploitation of technical vulnerabilities, (2) exploitation of social vulnerabilities through *'social engineering'* and (3) infecting cyber-systems with *'malware'* (mal-(icious soft)-ware) through technical and/or social vulnerabilities (NIST 2012; Choo 2011). The first category of attacks relies often on recently discovered technical vulnerabilities of cyber-systems. Before system owner have time to fix the vulnerability; attackers can access, steal or modify data, and sometimes gain full access to cyber-system (NIST 2012) . *'Social engineering'* is the *'technique of manipulating the user's psychology by exploiting trust* (Sood & Enbody 2014). This widely used type of attack tricks users with legitimately designed e-mails (*'Phishing'*) to share their personal information (Sood & Enbody 2014). Attacks conducted through the usage of *'malware'* are the third type of attacks, with very severe consequences (Choo 2011). Malware is *'software whose intent is malicious, or whose effect is malicious (…)* (Aycock 2006). Different types of malware exist; all of which are different in sophistication, intention and required effort to disclose (Aycock 2006)(see *Table 3* for summary).

<u>Cyber-vulnerability</u>

Vulnerabilities are paths attackers choose to penetrate a cyber-system (Anderl et al. 2013). Based on an approach used by the US Air Force Laboratory, Hughes & Cybenko (2014) identified three factors driving cyber vulnerability: (1) System susceptibility, (2) threat accessibility and (3) threat capability. According to the authors, these three attributes must exist for cyber-attacks to successfully penetrate a cyber-system.

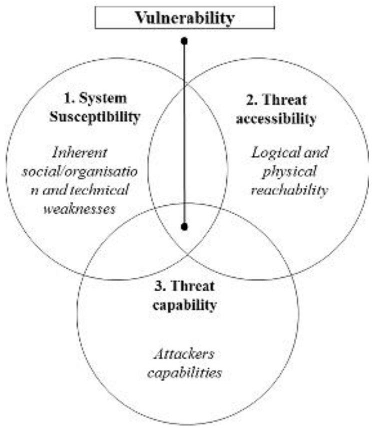

Figure 9: Cyber vulnerability (Hughes & Cybenko 2014)

System-susceptibility

The system-susceptibility is considered as inherent to the system due to social/organisational or technical flaws (Hughes & Cybenko 2014). The former are affected by the behaviour of staff within a firm, the latter are triggered by design trade-offs leading to inherent weaknesses (Mirjalili & Lenstra 2010; Hughes & Cybenko 2014) Based on views of different authors, standards and reports, a classification of these vulnerability factors were synthesised and compiled (see *Table 4*).

Social/organisational *'weaknesses'* arise due to, for example, inadequate staff qualification or unawareness with regards to security guidelines. These weaknesses are exploited by attackers through *'social engineering'*, as described earlier

Table 3: Classification of malicious software and cyber threats

Classification of cyber-threat provoking malware types			
Type of Malware	***Description***	***Sub-types***	***Threat classification***
Viruses (Aycock 2006) (Simmons et al. 2014) (KasperskyLab 2016)	• Attached to executable file, require a host program/human to open the file in order to run the virus • Able to replicate itself (Aycock 2006) (KasperskyLab 2016) (Simmons et al. 2014)	• File infector virus • Boot sector virus • Master boot record virus • Multipartite virus • Macro virus (Simmons et al. 2014)(Symantec Cooperation 2016)	• **Spoofing** Unauthorised access to system in order to steal confidential information, or access to confidential information • **Tampering** Maliciously modifying data in storage, data in process, data in transmission • **Repudiation**: Malicious act conducted without the possibility of being tracked back, attacker is disguising its attack • **Information Disclosure**: Exposing data to parties who do not have authority to see data • **Denial of Service:** host based, networked based, distributed; Attacks harming the availability of an IT-System (Simmons et al. 2014) • **Elevation of privilege** Attacker maliciously lifts up its privilege and gains almost full or full access to IT system; in this case, all the above mentioned threats are possible (BMWi 2016) (Microsoft 2005) (Howard 2006) (Simmons et al. 2014)
Trojan (Aycock 2006) (KasperskyLab 2016)	• Social engineering (e.g. fake email, fake website etc.) often used to manipulate user with disguised file • Capable of stealing data, modifying data and granting access to intruders (Aycock 2006) (KasperskyLab 2016) (Simmons et al. 2014)	Most relevant • Backdoor (gives remote control) • Exploit (take advantage of technical vulnerability) • Rootkit (prevents malicious activity to be detected) • DDos (against targeted website) (KasperskyLab 2016)	
Worms (Aycock 2006) (Simmons et al. 2014) (KasperskyLab 2016)	• Very harmful as worms capable to replicate and spread themselves without any necessary activity from user • Do not have to be opened by user (Aycock 2006) (KasperskyLab 2016) (Simmons et al. 2014)	• Net-Worm • Email-Worm • IM-Worm • P2P-Worm • IRC-Worm (KasperskyLab 2016)(Simmons et al. 2014)	
Ransomware (Aycock 2006) (Simmons et al. 2014) (KasperskyLab 2016)	• Threats user in harming 'availability', integrity' or 'confidentiality' of systems • User has no access to system unless attacker gets required information, finance etc. (KasperskyLab 2016) (Aycock 2006)	Examples of ransomware • Cryptolocker (2013) • Cryptowall (2013) • TorrentLocker (2014) • TeslaCrypt (2015) • SamSam (2016) • Locky (2016) • Cerber (2016) • Petya and Mischa (2016) • CryptXXX (2016) • Jigsaw (2016) (You & To 2016)	
Spyware (Aycock 2006) (Simmons et al. 2014) (KasperskyLab 2016)	• Malware which is deployed on system to monitor confidential information (Aycock 2006) (KasperskyLab 2016) (Simmons et al. 2014)		

Technical *'weaknesses'* emerge due to flaws in the software, network or hardware. The CWE database of the MITRE corporation has reported an increase of the number of software vulnerabilities from 2450 in 2004 to a total 7846 in 2014 (MITRE Corporation 2016).

Threat-accessibility

System-susceptibility cannot be exploited without access to the system (Bodhani 2015; Dunn Cavelty 2014). Hence, key *'ingredients'* to cyber vulnerability are unprotected communication lines (networks) or insecure network architectures.

Threat-capability

Once technical susceptibilities are exposed to the public the likelihood of an attacker having success with malicious intentions depends upon their incentives, level of expertise and tools (Hughes & Cybenko 2014). Hence, it is necessary to identify potential attackers and their incentives (Boyes 2015). Adapted from BMWi (2016) and complemented with criteria identified by the World Economic Forum (2015), Boyes (2015) and Choo (2011), *Table 5* provides a classification of cyber-attackers.

Table 4: System susceptibility (Factor of vulnerability)

System susceptibility (one factor of system vulnerability)					
A. Social/ Organisational	**B. Technical**				
	B1. Software			***B2. Network***	***B3. Hardware***
	B11. Flaw Type	*B12. Flaw Time of introduction*	*B13. Location of flaw*		
• Staff qualification or competence insufficient • Staff lack of motivation to follow security practices • Poor communication • Inadequate security awareness • Harmful intention • Key person / knowledge dependency (CRO Forum 2016) Leading to: • Downloading infected file from the internet • Peer-to-Peer file sharing (e.g. cloud) • Opening infected file attached to email • Accessing infected website (KasperskyLab 2016; Symantec Cooperation 2016)(Anderl et al. 2013)	Misconfiguration • Configuration flaw within particular application can be exploited by attacker Kernel flaws • Kernel is core code of an operating system, flaw could be exploited Design flaws Buffer overflow (Stack, Heap) • Happens when input length is not checked by code and consequently input value is not the length the program expects Insufficient authentication validation • *'An attacker can exploit insufficient authentication validation vulnerability'* Insufficient input validation • Input is failed to by validated by program Symbolic link (Simmons et al. 2014; Scarfone & Orebaugh 2008; Cowan et al. 2003)	During development • Requirement/Specification/Design • Source code • Object code (Landwehr et al. 1994) During implementation • During operation • malware which modified architecture could lead to more software vulnerabilities During maintenance • e.g. maintenance operators fail to understand holistic software system (Landwehr et al. 1994) (Landwehr et al. 1994)(Meunier 2008)	Operating System • System initialisation • Memory management • Process/management/scheduling • Device management (including I/O, networking) • File management • Identification/Authentication Support Comprises compilers, editors, debuggers, macro libraries, database management system • Privileged utilities (functions not anticipated when operating system was built) • Unprivileged utilities • Application (Landwehr et al. 1994)	• Unprotected communication lines • Insecure network architecture (ISO/IEC FIDIS 27005:2008 2008) Is both a technical susceptibility and relevant factor for system vulnerability (ISO/IEC FIDIS 27005:2008 2008)	• Susceptibility to humidity • Susceptibility to dust • Susceptibility to soiling • Susceptibility to unprotected storage (ISO/IEC FIDIS 27005:2008 2008)

Table 5: Cyber attacker classification

Potential cyber attackers, incentives, and capabilities			
Attacker type	***Description***	***Incentive***	***Capabilities***
User (BMWi 2016)	• Usually no criminal intentions • Manipulation attempt of cyber system to facilitate workload (BMWi 2016)	• Avoid unnecessary/unwanted work procedures (Choo 2011) (BMWi 2016)	Low (BMWi 2016)
Staff with criminal intention (BMWi 2016)	• Deliberate intention to harm employer/organisation (BMWi 2016)	• Blackmail/Ransom • Revenge • Disguise misbehaviour • (BMWi 2016)	Low/Medium (BMWi 2016)
Petty criminals (BMWi 2016) (WEF 2015) (Boyes 2015)	• Compromising cyber system to limited extent • Usually not organised • Usually not part of criminal organisation (BMWi 2016) (WEF 2015) (Boyes 2015)	• Personal advantage • Financial interest (small scale) (Choo 2011) (BMWi 2016)	Low/Medium (BMWi 2016)
Script-Kiddies (BMWi 2016)	• People with no/little intention for criminal exploitation • Exploration of technical capabilities	• Hacking for attention or appreciation (Choo 2011)	Low/Medium (BMWi 2016

Cyber-risks

The ISO/IEC FIDIS 27005:2008 (2008) standard depicts cyber-risks as *'the potential that a given threat will exploit vulnerabilities of an asset or group of assets and thereby cause harm to an organisation'*. Hence, factors attributing to risk comprise assets targeted, aspects of assets disturbed/harmed as well as consequences (for vulnerabilities see previous chapter). An overview of these risk factor is presented below.

Table 6: Cyber risks

Components of cyber risk		
Assets targeted	***Attributes affected***	***Consequences***
• Data • Information • Component • Processes • Intellectual Property • Reputation • Safety (BMWi 2016; Boyes 2015; Simmons et al. 2014; Aycock 2006; Hult & Sivanesan 2013a)	**CIA-Triad'** Confidentiality • Harming the confidentiality of data could lead to unauthorised disclosure of information (Perrin 2008; Lighari et al. 2014; Mirjalili & Lenstra 2010; Windelberg 2016; Stoneburner 2001; NIST 2004) Integrity • Harming the integrity of data could lead to unauthorised modification/destruction of information and information systems (Perrin 2008; Lighari et al. 2014; Mirjalili & Lenstra 2010; Windelberg 2016; Stoneburner 2001; NIST 2004) Availability • Harming the availability of data could lead to disruption of access or the use of information or an information system (Perrin 2008; Lighari et al. 2014; Mirjalili & Lenstra 2010; Windelberg 2016; Stoneburner 2001; NIST 2004)	**Consequences on business level activities** • Disclosure of confidential information • Theft of confidential information • Modification of information • Malfunction of applications used • Lost access to application • Disruption of business processes • Delay of business processes • Wrong execution of business processes • Wrong decisions affecting business processes etc. **Consequences on operational level activities** • Espionage of production processes • Espionage of production system • Espionage of Intellectual property • Manipulation of functionality of machine • Unplanned downtime of machine • Manipulation of production schedule • Defects in products **Consequences on operational level activities** • Financial damage • Reputational damage • Safety issues (Piggin 2014; Khan & Estay 2015; BMWi 2016; Anderl et al. 2013)

Conceptual framework for data collection

To address key research areas associated with the research question, a holistic framework is proposed (see *Figure 10*), which synthesises the knowledge streams and developed sub-frameworks introduced in the literature review. Closer examination of the framework reveals that the order of key research areas is aligned with the sub research questions.

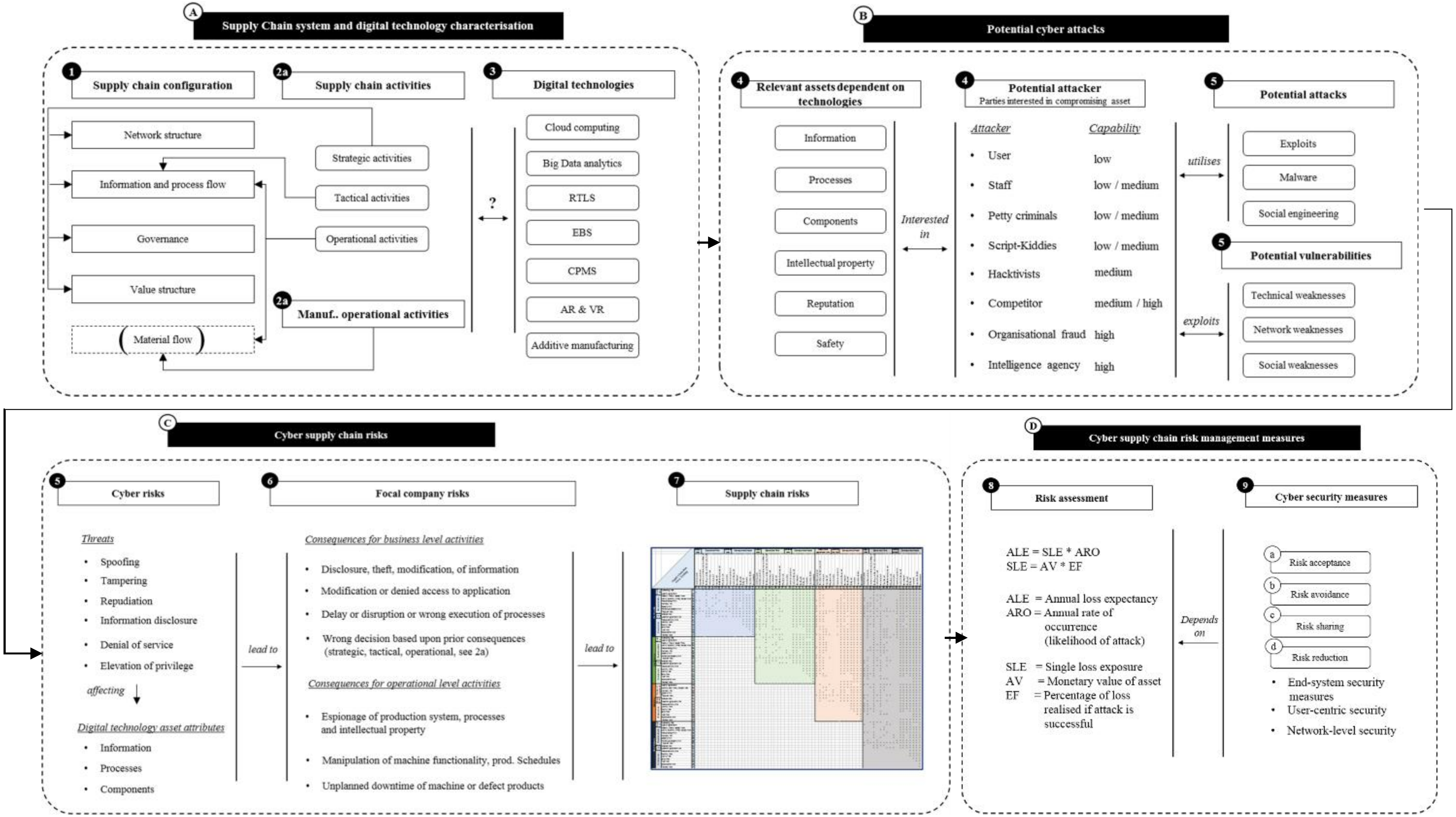

Figure 10: Final framework: big picture

Research approach

The research methodology deemed suitable for this paper was *'explorative case-study'*. Employing case studies enabled to gain insight from cyber security actors currently practicing the discipline through various sources of data (Yin 2009). Also, the research question guiding this paper is open-ended and requires rather explorative field studies to generate new theory (Edmondson & Mcmanus 2007).

The detailed research design for this research project is presented in *Figure 11*.

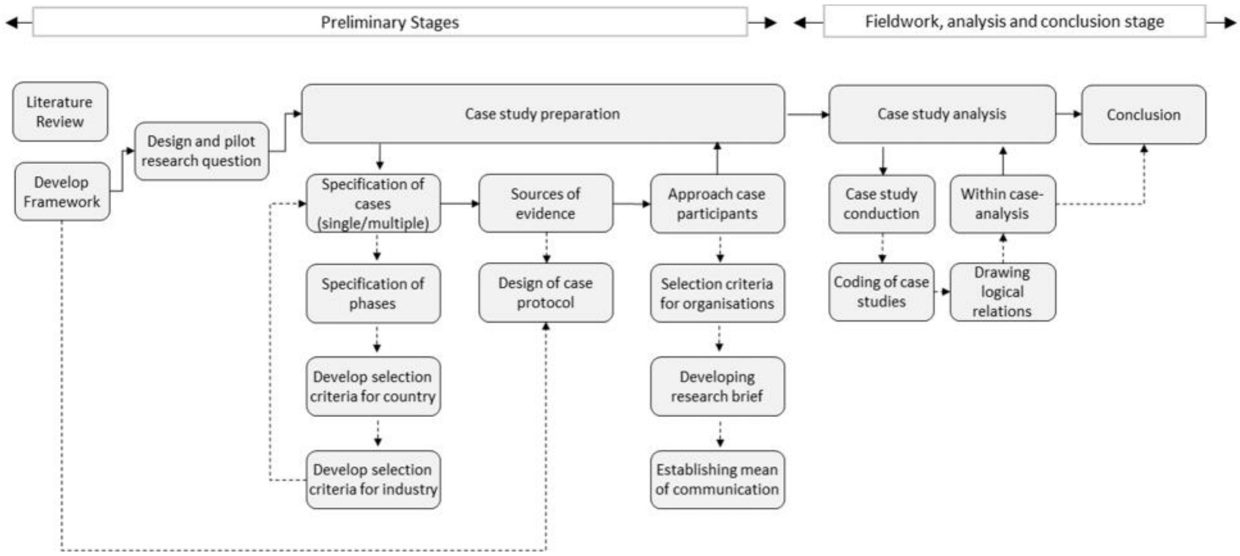

Figure 11: Research component design (further developed from Noor (2008)

For the literature review, a total of 300 publications were gathered, of which approximately 200 were screened and 100 thoroughly analysed. The following methodology for literature review was applied (developed from Denyer & Pilbeam 2013)

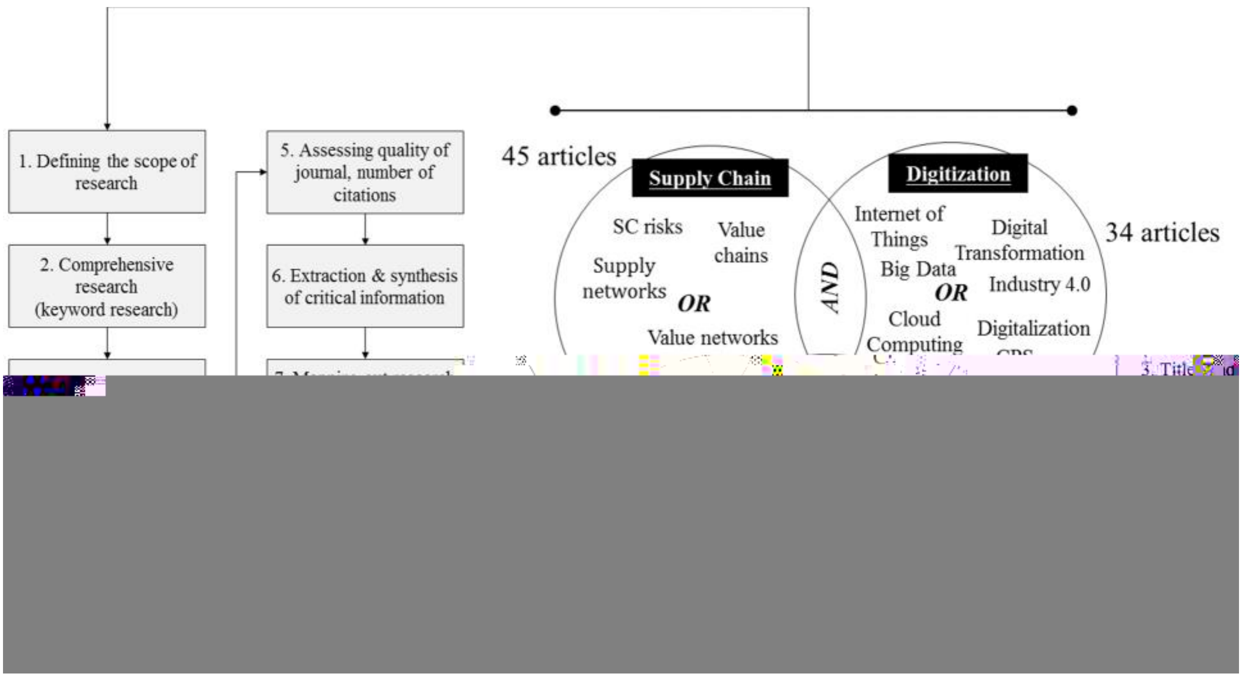

Figure 12: Methodology for literature review developed from (Denyer & Pilbeam 2013)

Case study design

The case study design refers to the number of cases conducted as well as the unit of analysis (Yin 2009). Four different types of case studies emerge (see *Figure 13*). The case study for this paper will be carried out as a single case study with a single unit of analysis.

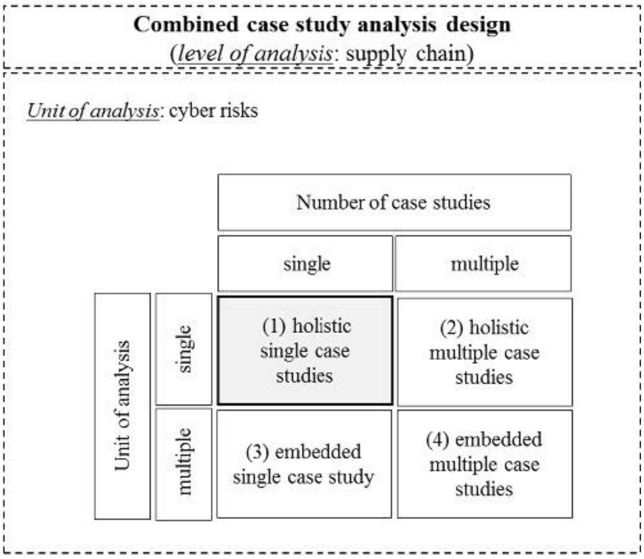

Figure 13: Case-study-design

Vital stakeholders related to cyber risks were identified as follows: (1) external cyber-security firms developing security technologies; (2) cyber-security-divisions within OEMs; (3) cyber-security government-bodies initiating policies to foster cyber security and finally, (4) cyber-security research institutions who operate on the intersection between academia and industry. To identify appropriate country for field research, market analysis was carried out. It was evident that the most targeted country was the US (Statista 2016). Across Europe, the UK and Germany were found to be most frequently attacked (CNBC 2014). Combined with the stakeholder analysis, the case was introduced as

- Cyber security expert companies, cyber security divisions within OEMs, cyber security government bodies and cyber security research institutions across the US, UK and Germany

As a primary source of evidence, this paper relied on interviews as these provide valuable insight in a contextual manner. Yin (2003) points to the (1) *'response bias'* and (2) *'inaccuracies due to poor recall'* as two major disadvantages of interviews. However, the first challenge is countered in this paper through multiple interviewees per case (*'data triangulation'*). The second challenge is embraced in using a sound voice recorder.

Due to the explorative nature of this paper, the interviews were carried out in a semi-structured fashion (Edmondson & Mcmanus 2007). This allowed enough flexibility during the interview to interact with the expert and guide the conversation towards the targeted research area. The case protocols (questionnaire) were iteratively adjusted to follow the data inductively and place emphasis on important issues (Edmondson & Mcmanus 2007).

The organisation selection process considered both suitability and likelihood of organisations to participate. Thorough market research was carried out. It was found that those organisations (and individuals within those organisations) who contributed to reports with regards to cyber security were best suited to be interviewed. The list of participants is provided in *Figure 14*.

The names are coded along with the organisations due to confidential reasons. However, the type of organisation and position of participants are disclosed upon agreement.

Case study organisation and interviewee list phase 2					
	Nr.	***Industry of organisation***	***Type of organisation***	***Size***	***Position Interviewee***
Case 2	1	Cyber security	Cyber security firm focused on industrial systems (USA)	n/a	Managing Partner
	2	Technology provider	Leading technology systems provider for automotive and pharmaceutical etc.(Germany)	>5 bill. €	Senior Director Business Development
	3	Technology provider	Leading technology and component provider for automotive and electronics (Germany)	>50 bil. €	Cyber Security Specialist
	4	Electronics	Leading Electronics OEM (Site in Germany)	>30 bil. €	Cyber Security Program Manager
	5	Aerospace	Leading aerospace OEM supplier (United Kingdom)	>10 bil. €	Cyber Security Specialist
	6	Government	Government institution for Information Security	n/a	Cyber Security Specialist
	7	Advisory	Technology advisory firm (worldwide)	>10 bil. €	Head of Cyber Security
	8	Research Institution	Leading German Research Institution	n/a	Director Software Technology
	9	University	Leading Engineering University in Germany	N(a	Professor for Encryption

Figure 14: List of participants

The analytical strategy for this paper is the development of a case description. This case description was already introduced as a conceptual framework and shapes the case. As an analytic technique, the data analysis consists of a single within-case analysis. Miles & Huberman (1994) suggested the application of matrixes and data displays (graphs), as well as coding of interviews, which are heavily used in this paper.

Three common rules were established to assess the quality of this explorative empirical research (Yin 2003). The table below elaborates on each criterion and provides the extent to which these were ensured during this project.

Table 7: Quality of Case Study Design

Quality of research design (adopted from Yin (2003)			
Criteria	*Tactics to ensure quality*	*Stage*	*Application to this research project*
Construct validity	• A. Use multiple sources of evidence • B. Establish chain of evidence • C. Have key informant draft case study report	Data collection	• A. Used primary and secondary data • B. Is ensured as the case study questions (research question) determined case study protocol, which was used to collect evidentiary data write up a case report • C. Could not be fully conducted due to the amount of interviews and time constraint of interviewees
External validity	• A. Use theory in single case studies • B. Use replication logic in multiple case studies	Data analysis	• A. The theory that lead to the single case study in the first place can also be used to identify applications in which the case might be relevant as well • Theoretical replication was used across the multiple cases; i.e. different aspects were viewed
Reliability	• A. Use case study protocol • B. Develop case study database	Data collection	• A/B: Case study protocol will be added to this work with different iterations. This ensures that another researcher would come to the same conclusion under the same circumstances • A/B: Generally, each step followed during this project is documented in a detailed manner and attached to the addendum. The level of detail was such that even an exemplary e-mail was attached, which was used to approach the organisations

Results

This chapter covers findings to answer the following sub-research question

- 1st: What are the cyber-vulnerabilities associated with DTs
- 2nd: What are the cyber-risks associated with DTs
- 3rd: What are the mitigation strategies to reduce cyber-risks

From ***Table 8*** the following conclusions can be drawn

- Potential cyber-vulnerabilities
- Cyber-vulnerabilities associated with DTs (context-specific)

From ***Table 9*** the following conclusions can be drawn

- Potential cyber-risks
- Cyber-risks associated with DTs (context-specific)

From ***Table 10*** the following conclusions can be drawn

- Potential cyber-risks mitigation strategies
- Cyber-risk mitigation strategies associated with DTs (context-specific)

Table 8: Data analysis - Technology groups, security attributes, vulnerabilities and attacks

Data analysis (I)

Technology groups, associated security attributes, vulnerabilities and attacks

Criteria	1.Security attributes of assets (which sequence?)			2. Vulnerabilities							3. Attack type	
				2A. Technical vulnerabilities					2B. Social			
Technology groups	**Confidentiality** of information	**Integrity** of processes	**Availability** of processes and components	Software error due to **wrong development**	Software error application (**vendor specific**)	**Outdated** systems	**Poor access control**	**Loosely encrypted databases**	**Poor passwords**	**Disobey to guidelines**	Deploying malware exploiting **technical vulnerability**	Deploying malware using **social engineering**
Group A: Supply network configuration technologies												
A1. Platforms for automated inf. flow (cloud-based)	1. CS1… CS5, CS8, CS9	2. CS1… CS5, CS8, CS9	3. CS1… CS5, CS8, CS9	CS1; CS4…CS9	CS4 … CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
A2. (small) data analytics				CS1; CS4…CS9	CS4- CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
Group B: Coordination of information and physical material flow (tactical and operational supply chain activities)												
B1. Platforms for automated inf. flow (cloud-based)	3. CS7	1. CS7	2. CS7	CS1; CS4…CS9	CS4- CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
B2. (small) data analytics				CS1; CS4…CS9	CS4- CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
B2. RFID/GPS/GSM/GPRS for inter-logistics track & trace				CS1; CS4…CS9	CS4- CS9.	-	CS6	CS6	-	-	CS6	-
Group C: Generation of physical material and intra-logistics (manufacturing and intra-logistics)												
C1. Platform for automated inf. flow (cloud-based)	3. CS 1-5, CS8, CS9	2. CS 1-5, CS8, CS9	1. CS 1-5, CS8, CS9	CS1; CS4…CS9	CS4- CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
C2. (small and big) data analytics				CS1; CS4…CS9	CS4- CS9.	-	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS9	CS1… CS9
C3. RFID for intra-logistics				CS1; CS4…CS9	CS4- CS9.	-	CS6	CS6	-	-	CS6	-
C4. Embedded systems				CS1; CS4…CS9	CS4- CS9.	CS2 & CS3	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS3	-
C5. Machine-to-X communication				CS1; CS4…CS9	CS4- CS9.	CS2 & CS3	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS3	-
C6. Augmented and virtual reality				CS1; CS4…CS9	CS4- CS9.	-	-	-	-	-	CS1…CS3	-
C7. Additive manufacturing (general manufacturing processes)				CS1; CS4…CS9	CS4- CS9.	CS2 & CS3	-	-	-	-	CS1…CS3	-
C8. Cyber-physical logistic/manufacturing systems				CS1; CS4…CS9	CS4- CS9.	CS2 & CS3	CS7	CS7	CS1, CS3, CS6…7	CS3…CS8	CS1…CS3	-

Table 9: Data analysis - Cyber risks due to various types of attacks

Data analysis (II)

Cyber risks due to various types of attacks

Technology groups	**4. Cyber risks**																	
	4.1. Sensitive data breaches					**4.2. Disruption/Delay of material flow** (quantity, quality, time)										**4.3. Digital lifecycle affected**		**4.4 Safety**
	4.1.1. Sensitive data			4.1.2 Intellectual property		4.2.1 Coordination compromised								4.2.2 Execution compromised				
	...ling/accessing ...stomer data	...ing business data ...volume, finance)	...ssing / stealing ...upplier data	...g IP of products	...g IP of processes	...ing data such that ...c decisions wrong	...emand data ...ompromised	...er placing data ...ompromised	...ination material ...ata compromised	...ne applications for ...al flow shutdown	...work shutdown	...m order placing ...shutdown	...form for order ...ving shutdown	...ulation of manuf. processes	...hutdown of ...acturing systems	...ating firmware on products	...vious modification ...oducts (re-call)	...us manipulation ...turing process

Table 10: Data analysis - Cyber risks reduction and avoidance strategies

Data analysis (III)

Cyber reduction and avoidance strategies

Technology groups	**4. Cyber risk management**																			
	4.1. Risk reduction																			
	4.1.1 End-system security										**4.1.2 Communication security**					**4.1.3 Network security**				**4.1.4 General**
	Access control (mutual authentication)	Access control via hardware (dongle)	Encrypted data storage	Virus scanner	Intrusion detection (non-time-critical systems)	Patch-Management (for non-time-critical systems)	Patch-management with 2-CPU (time-critical system)	Application-White-Listing (non-time & time-critical)	DDoS-prevention	Logical separation control and communication unit	Encryption (for non-time critical)	VPN	Raspberry pie (does encryption, authentication)	Enterprise-Digital Rights management	OPC-Unified Architecture	Firewalls (before web and within network)	DMZ	Network segmentation	Encapsulation	Penetration testing, social eng. countermeasures
Group A: Supply network configuration technologies																				
A1. Platforms for automated inf. flow (cloud-based)	CS7, CS4	CS2, CS6	CS7	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS 2,6,6, 8,9	-	CS3 CS4	CS6	-	CS2 CS4 CS8	CS2 CS4 CS8	-	CS3	-	CS2 CS4	CS2 CS4	CS5	CS2	CS4 CS8
A2. (small) data analytics	CS7, CS4	CS2, CS6	CS7	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS 2,6,6, 8,9	-	CS3 CS4	-	-	CS2 CS4 CS8	CS2 CS4 CS8	-	-	-					
Group B: Coordination of information and physical material flow (tactical and operational supply chain activities)																				
B1. Platforms for automated inf. flow (cloud-based)	CS7, CS4	CS2, CS6	CS7	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS3, CS7	CS3 CS4	CS6	-	CS2 CS4 CS8	CS2 CS4 CS8	-	CS3	-	CS2 CS4	CS2 CS4	CS5	CS2	CS4 CS8
B2. (small) data analytics	CS7, CS4	CS2, CS6	CS7	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS 2,6,6, 8,9	CS3, CS7	CS3 CS4	-	-	CS2 CS4 CS8	CS2 CS4 CS8	-	-	-					
B2. RFID/GPS/GSM/GPRS for inter-logistics track & trace	CS2	-	-		-	-	-	-	-	-	CS2 CS4 CS8	-	-	-	-					
Group C: Generation of physical material and intra-logistics (manufacturing and intra-logistics)																				
C1. Platform for automated inf. flow (cloud-based)	CS7, CS4	CS2, CS6	-	-	-	-	CS3, CS7	CS3 CS4	CS6	-	CS2 CS4 CS8	CS2 CS4 CS8	-	CS3	-	CS4 CS5	CS2 CS4	CS5	CS2	CS4 CS8
C2. (small and big) data analytics	CS7, CS4	CS2, CS6	-	-	-	-	CS3, CS7	CS3 CS4	-	-	CS2 CS4 CS8	-	-	-	-					
C3. RFID for intra-logistics	CS2	-	-	-	-	-	-	-	-	-	CS2 CS4 CS8	-	-	-	-					
C4. Embedded systems	CS7, CS4	CS2, CS6	-	-	-	-	-	CS3 CS4	-	CS5	CS2 CS4 CS8	CS2 CS4 CS8	-	-	CS3					
C5. Machine-to-X communication	CS7, CS4	CS2, CS6	-	-	-	-	-	CS3 CS4	-	CS5	CS2 CS4 CS8	CS2 CS4 CS8	CS2	-	CS3					
C6. Augmented and virtual reality	CS7, CS4	CS2, CS6	-	-	-	-	-	CS3 CS4	-	CS5	CS2 CS4 CS8	-	CS2	-	CS3					
C7. Additive manufacturing (general manufacturing processes)	CS7, CS4	CS2, CS6	-	-	-	-	-	CS3 CS4	-	CS5	CS2 CS4 CS8	-	CS2	-	CS3					
C8. Cyber-physical logistic/manufacturing systems	CS7, CS4	CS2, CS6	-	-	-	-	-	CS3 CS4	-	CS5	CS2 CS4 CS8	CS2 CS4 CS8	CS2	-	CS3					

Discussion

This chapter first delves into conflicting security attributes (CIA) of DTs. Then, the findings of the case will be discussed to answer the following three research-questions:

- 1st-sub-question: What are the cyber-vulnerabilities associated with digital technologies of a DSC?
- 2nd-sub-question: What are the cyber-risks associated with digital technologies of a DSC?
- 3rd-sub-question: What are the cyber-risk mitigation strategies associated with digital technologies of a DSC?

Finally, a cyber-resilience framework is proposed.

Conflicting security attributes

This paper reveals that the *cyber-vulnerabilities, cyber-risks and cyber-risk-mitigation strategies* of a particular digital technology cannot be simply defined. *'They strongly depend on the context in which the technology is used'*, according to CS9 (see *Table 8*). The context determines the security attributes to protect (confidentiality, integrity or availability – CIA-Triad).

A brief example should provide more clarity: The procurement division of a company uses a platform to pass an order to the supplier. This order also includes a technical drawing, which is a core intellectual property of a company. The company's interest is that this information is passed on to the supplier as secure as possible. Hence, *confidentiality* is the core attribute to secure. However, the logistics division in a firm has different requirements. They use platforms to coordinate the material in real-time across the supply chain. Re-configuration decisions need to be passed on immediately, 24 hours a day. Hence, their security attribute to the platform is *availability*.

The example above indicates that a *'platform'* has two varying security attributes (confidentiality and availability), depending on its context. However, these security attributes are conflicting, as stated by CS2-CS9.

Strikingly, *'in DSCs the number of these cases with conflicting security attributes is constantly increasing'* (CS2). This is one of the biggest challenges DSCs are facing (CS4). Cyber security experts are not accustomed to this situation (CS2). In the past, the most important attribute to ensure was confidentiality. Hence, all security measures were designed according to this requirement, as stated by CS1. However, as DSCs are also about controlling the material flow in real-time and over the internet, the importance of availability now is significantly increasing. And it is not about making a decision as to which attribute should be emphasised more; it is about *'how to protect all security attributes of all technologies collectively'*, as stated by CS2.

To address all security-attributes (CIA) of all technologies collectively, a framework is required. This framework should depict various technologies along with their *'security-attributes'* and *'exposure to the public web'* on a chart. The following framework is proposed as *'the foundation for cyber security in digital supply chains'* to meet the requirement described above.

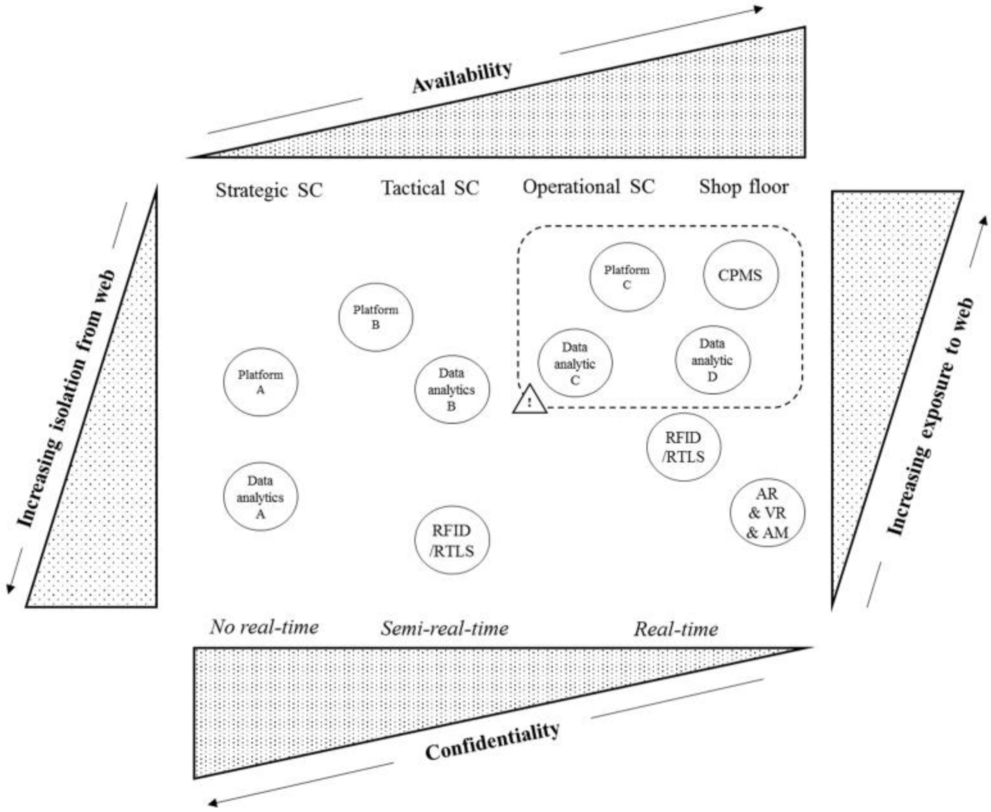

Figure 15: The foundation of cyber security in digital supply chains

Firms can place their technology-portfolios on this framework, depending on their *'context'*, *'security-requirements'* and *'exposure to the public web'*. In doing so, firms are able to identify the technologies which require special attention: **high availability** and **high exposure to web** technologies (upper-right corner). This knowledge is important as those technologies are characterised by additional cyber-vulnerabilities, additional cyber-risks and limited number of mitigation-strategies. Throughout the following chapters it become apparent as to why these technologies require special attention.

Cyber-vulnerabilities (1st-sub-research question)

This paper reveals that cyber-vulnerabilities in DSCs can be classified into *'technical'* and *'social vulnerabilities'*.

Technical vulnerabilities

It can be inferred from *Table 8* that technical vulnerabilities of DTs in a DSCs can be categorised into 4 types:

a) Software error due to wrong development

b) Software error due to applications acquired from vendors outside the firm

c) Poor access control

d) Loosely encrypted databases

e) Outdated systems

This novel categorisation enables firms to immediately focus on those vulnerabilities relevant to DSCs. How each of these vulnerability types is relevant to particular DT can be concluded from *Table 8*.

Usually, most vulnerabilities can be fixed with patches (updates) released by the vendors. However, this paper reveals that there is one exceptionally threating vulnerability to DTs not solvable with patches: *'Outdated systems'*.

This is where the framework needs to be considered. Those technologies on the upper right area are characterised through high availability and high exposure to the public-web. These could be platforms coordinating the material flow in real-time, or machines on the shop-floor. The operating systems these technologies are deployed on tend to be outdated, because updating a system to fix a technical flaw would require the entire system to shut down (TP9). CS4 states *'that those familiar with manufacturing know that every minute of plant-downtime would cost companies often £100,000*. Hence, they are not willing to accept this loss (CS4). Due to this phenomenon the technologies on the upper right corner (of the framework) are weakened by the minute they are exposed to the public-web or the business-IT systems, as reported by CS2. Thus, becoming an easy target for attackers (*'black-hat-hackers'*). Once these weak links are exploited, malware can easily reach up to business-IT and R&D-levels, where important intellectual property is located at, as stated by CS8.

Social vulnerability

To point the attention of academics and practitioners likewise to the most important social vulnerabilities, this paper has defined a new categorisation (see *Table 8*):

a) poor passwords

b) disobey to guidelines

To capture how these vulnerabilities are relevant to particular DTs, *Table 8* can be consulted. This table provides the detailed answer to the 2nd sub-research question.[2]

It appears that social vulnerabilities are underestimated as the cause of cyber-risks among industrialists, as confirmed by CS2, CS4, CS5 and CS7. People are prone to believe that attackers always find the tiniest flaws in a system, and then exploits these. However, CS7 stated that *'when somebody really wants to get their hands in and steal information from the company they are not going to take the hardest door (technical vulnerability). That seems to be the view that most people take and that's a nice way to distract the world'*. Attackers are in fact disguising their malicious software in professionally designed e-mails (*'phishing'*), which are opened by a person within the company: the malware spreads across the entire network. CS8 introduced an incident where a company had secured its entire network communication, however, attackers bypassed these security layers in conducting social engineering: a malicious email opened with an iPad in the company network spread across the system and thus, provoked the malfunction of multiple applications and machines.

Social vulnerabilities are clearly a serious threat to firms. The reason as to why they are underestimated is that practitioners do not understand the way in which attackers are initiating an attack (see CS7 quote) and more importantly, because social vulnerabilities do not appear dangerous: Simply because a *poorly chosen password* or *disobey to guidelines* do not sound 'exciting', they are not less dangerous then a technical vulnerability, as stated by CS7. If this is not understood profoundly, DSCs cannot be defended against cyber-attacks.

[2] The linking of all digital technologies with associated cyber-vulnerabilities is too exhaustive to be repeated in the discussion

Cyber risks (2nd-sub-research question)

From the cases conducted it appeared that industrialists do recognise the threat of cyber-attack, however, they lack knowledge as to what particular cyber-risks they are exposed to. It becomes evident that there is clearly a gap among those initiating the decisions to implement digital technologies, and those securing digital technologies from cyber-attack, as confirmed by CS8. This is to an extent due to the fact that in the past, security experts were often located mainly on the office-floor levels, with focus on ensuring business-IT security, as stated by CS9. That those experts will also play a vital role in divisions where the actual material flow is coordinated, is not yet fully understood. Hence, the knowledge transfer and the understanding of what cyber-risks a DSC is exposed to, is very limited. This observation was made during the phase 1 cases and confirmed by CS5.

To close this gap, a pattern as to what these cyber-risks could be, was concluded. This pattern – or new categorisation of cyber risks – is depicted in *Figure 17*. The high-level categorisation is as follows

a) sensitive data breaches (intellectual property or business data breaches)

b) disruption/delay of material flow (coordination or execution compromised)

c) compromised digital lifecycle

d) safety

To capture the sub-categories of these risks, and how these are related to particular DTs, it should be referred to *Table 9*. This table provides the full answer to the 3rd-sub-research question.[3]

However, an example for each risk category is provided below to convey the severity of these cyber-risks.

a) Sensitive data breaches (*stealing IP of products*):

   An attacker could exploit social or technical vulnerabilities in both office-floor and shop-floor, to access valuable IP. CP2 states that in the automotive industry, managers have the suspicion that competitors were conducting cyber-espionage on new-development of product processes for years.

b) Disruption of material flow due coordination compromised (*forecast compromised*)

   Poor access control of simulation-tools calculating forecasts at firms further downstream the supply chain could be exploited by attackers. A slight change of parameters would affect the entire forecast, which would be disastrous for the entire upstream supply chain, as stated by CS9.

c) Compromised digital lifecycle (*Manipulation of firmware*)

   This is a very dangerous risk as it spans over the life-time of a product. As can be seen from the 'cyber-security-foundation'-framework (see Figure 23), CPMS are very vulnerable when connecting to ERP-systems or to the internet. An attacker could exploit these vulnerabilities to manipulate the firmware of the products the machine is

[3] The linking of all digital technologies with associated cyber-risks is too exhaustive to be repeated in the discussion

manufacturing. If these are the keys to cars (in automotive), CS4 states that attackers could prevent millions of cars from being unlocked with the key, unless the automotive company pays ransom.

c) Compromised digital lifecycle (Non-obvious manipulation of products)

Spans also over the life-time of a product. Attackers modifying the parameters of processes such that defects are produced which are not obvious immediately, could lead to product-recalls later on, according to CS9.

d) Safety (modification of manufacturing processes)

Attackers manipulating the controlling unit of machines could provoke not only a standstill, but change the processes such that even safety issues for the staff on the shop-floor arise, as stated by CS1.

The cyber-risks described above can be placed on the framework provided in *Figure 15*. The figure suggests the type of risks arising based on the location of a technology on the framework (see *Figure 16*).

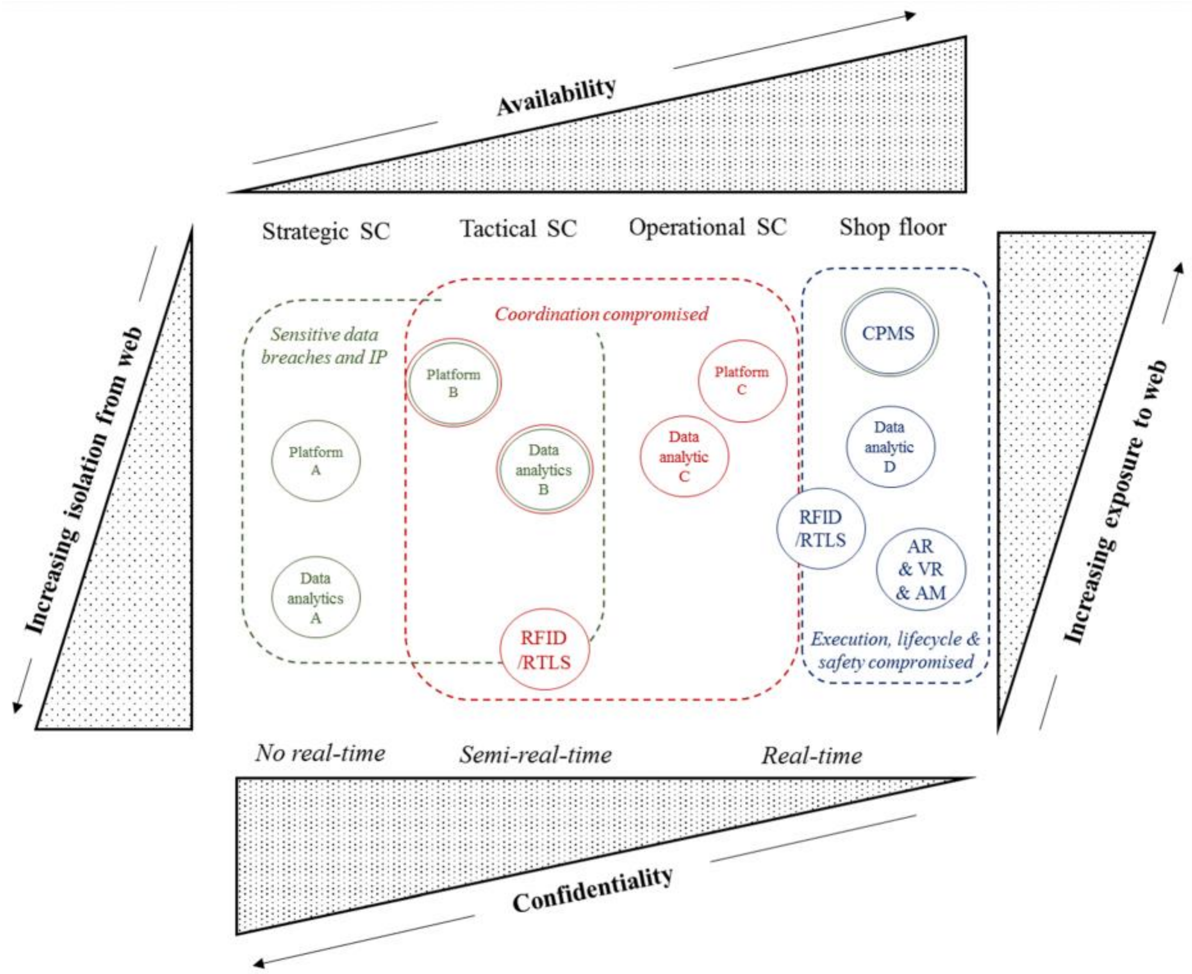

Figure 16: Digital technologies and their exposure to cyber-risk

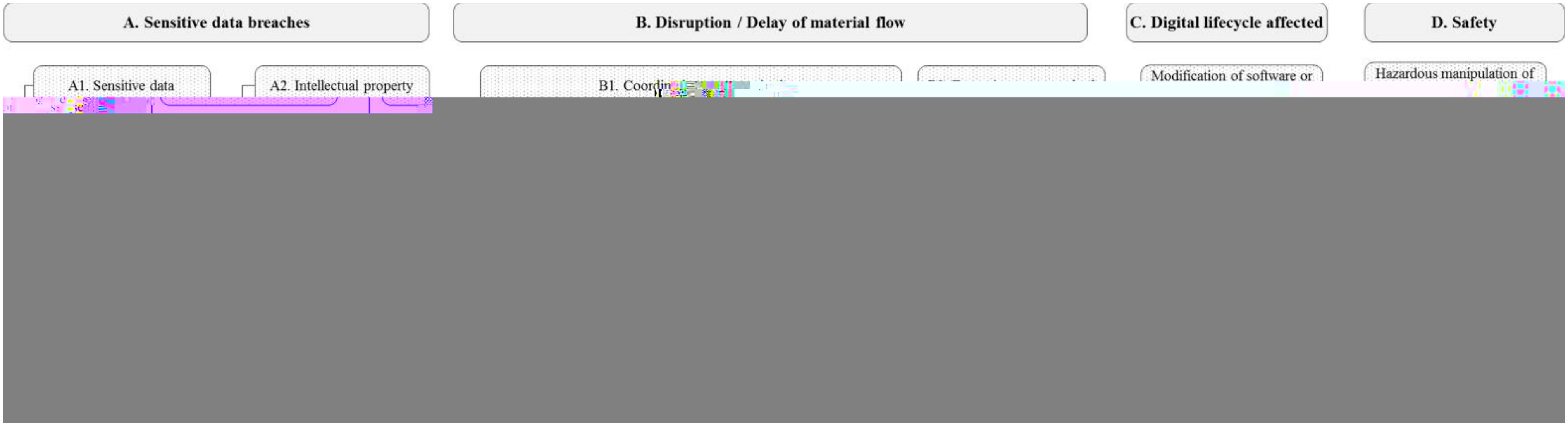

Figure 17: Cyber-risks in digital supply chains

Cyber-risks leading to supply-chain-risks

The cyber-risks at focal-company-level depicted in *Figure 17* have an impact on the subsequent supply chain. The impact of these cyber-risks on distributor and tier-1 customer can be inferred from the table below (developed from ***Error! Reference source not found.***). It becomes evident that cyber-risks can indeed lead to severe consequences for the entire supply chain.

Supply Chain Risk Stress Testing

Partner	Category	Code	Risk	Focal Company – Consequences: Stealing customer data risk	Stealing business data risk (financials)	Stealing supplier data risks	Stealing IP of product risks	Stealing IP of processes risks	Platform/algorithm for network configuration compromised	Platform/algorithm for forecasting compromised	Platform/algorithm for order placing compromised	Platform/algorithm for material flow coordination compromised	Shutdown of material coordination platform	Shutdown of manufacturing processes	Manipulation of firmware on products	Non-obvious modification of products (provoking product recall)	Hazardous manipulation of manufacturing processes
Tier-1 customer	Consequences/Impact	C7	Financial risks				*	*		*	*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C6	Reputational risks	*	*					*	*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C5	Trust risks	*	*					*	*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C4	Delay risk				*	*		*	*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C3	Quality risk								*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C2	Quantity risk							*	*	*	*	*	*	*	
Tier-1 customer	Consequences/Impact	C1	Product delivery risk							*	*	*	*	*	*	*	
Tier-1 customer	Deman d-side	D2	Customer agreement				*	*		*	*	*	*	*	*	*	
Tier-1 customer	Deman d-side	D1	Forecast risks														
Tier-1 customer	Operational Risks	O6	Intellectual property risk				*	*									
Tier-1 customer	Operational Risks	O5	Capacity risk							*	*	*	*	*	*		
Tier-1 customer	Operational Risks	O4	Inventory risk							*	*	*	*	*	*		
Tier-1 customer	Operational Risks	O3	Product design risk													*	
Tier-1 customer	Operational Risks	O2	Quality, quantity, or 'timely' output risk							*	*	*	*	*	*	*	
Tier-1 customer	Operational Risks	O1	Process or manufacturing capability risk											*			
Tier-1 customer	Supply-side	S2	Supplier agreement														
Tier-1 customer	Supply-side	S1	Purchasing risks	*	*					*			*				
Distributor	Consequences/Impact	C7	Financial risks							*	*	*	*	*	*	*	
Distributor	Consequences/Impact	C6	Reputational risks	*	*					*	*	*	*	*	*	*	
Distributor	Consequences/Impact	C5	Trust risks	*	*					*	*	*	*	*	*	*	
Distributor	Consequences/Impact	C4	Delay risk							*	*	*	*	*	*	*	
Distributor	Consequences/Impact	C3	Quality risk												*	*	
Distributor	Consequences/Impact	C2	Quantity risk							*	*	*	*	*			
Distributor	Consequences/Impact	C1	Product delivery risk							*	*	*	*	*			
Distributor	Demand-side risks	D2	Customer agreement							*	*	*	*	*			
Distributor	Demand-side risks	D1	Forecast risks														
Distributor	Supply- and operational	O5	Capacity risk							*	*						
Distributor	Supply- and operational	O4	Inventory risk							*	*						
Distributor	Supply- and operational	O2	Quantity or 'timely' output risk							*	*	*		*			
Distributor	Supply- and operational	S2	Supplier agreement	*	*												

Figure 18: Impact of cyber-risks (focal company) on subsequent supply chain

Cyber risks – mitigation strategies (3rd-sub-research question)

A categorisation of cyber-risk mitigation strategies in DSCs was developed from *Table 10* and is presented below, along with one example per category. The detailed security-technologies relevant for each DT can be concluded from *Table 10*.

a) *End-system security (protection of end-system)*

   'Access control via hardware (USB-dongle)': Is applied on end-systems to prove authentication and authorisation of user (TP1). If *'dongle'* is not plugged-in, DT will not be accessible. Hence, it provides security against both malware and social engineering attacks.

b) *Communication security (protection of data in transit)*

   'Virtual-private-network (VPN)': Establishes a virtual-private-network between two parties to transmit confidential information. Is 'virtually' cut-off from the public-domain and hence, usually not accessible for attackers (TP3).

c) *Network security (prevent attackers from intruding into the network)*

   'Network segmentation': Established virtual sub-networks within a firm so that malware in one sub-network cannot spread into another sub-network (CS5). For example, procurement-division and sales-division could be spread into two sub-networks to reduce impact in case of a successful attack on either division.

d) *General security measures*

   'Social-engineering-education': Firms can hire professional security-companies who deliberately conduct social-engineering attacks on firm to educate staff and raise awareness (CS8).

In spite of the number of security-technologies available, companies should not assume that these provide full security, as stated by CS6. Many mitigation strategies are designed such that they can only detect known malware, which is referred by CS8 to as *'protecting against the past'*.

The rationale behind this statement: unknown malware, or in other words, *'attacking-tools'* not know to security-firms or databases, can still affect highly-secured systems (CS3). To counter this threat, firms must update their security-technologies on a regular basis to provide full security, as stated by CS1.

From a security-technology perspective, DTs can be clustered into two groups (see *Figure 19*):

- DTs with numerous security-technologies applicable (dotted green line)
- DTs with limited security-technologies applicable (dotted red line)

Those DTs encircled by the dotted green line can be supported by numerous security measures. However, the DTs encircled by the dotted red line require special attention. This is due to the high availability these DTs require. To understand the rationale behind this, one has to understand how security measures work:

Encryption, for example, is one of the cheapest and most effective communication security measures and hence, widely used (CS2-CS9). However, this security measure slows down the data traffic. As a result, DTs sending/receiving data in real-time cannot rely on encryption. It appears that this is a challenge companies are indeed struggling with, as confirmed by TP1, TP2, CS4 and CS8.

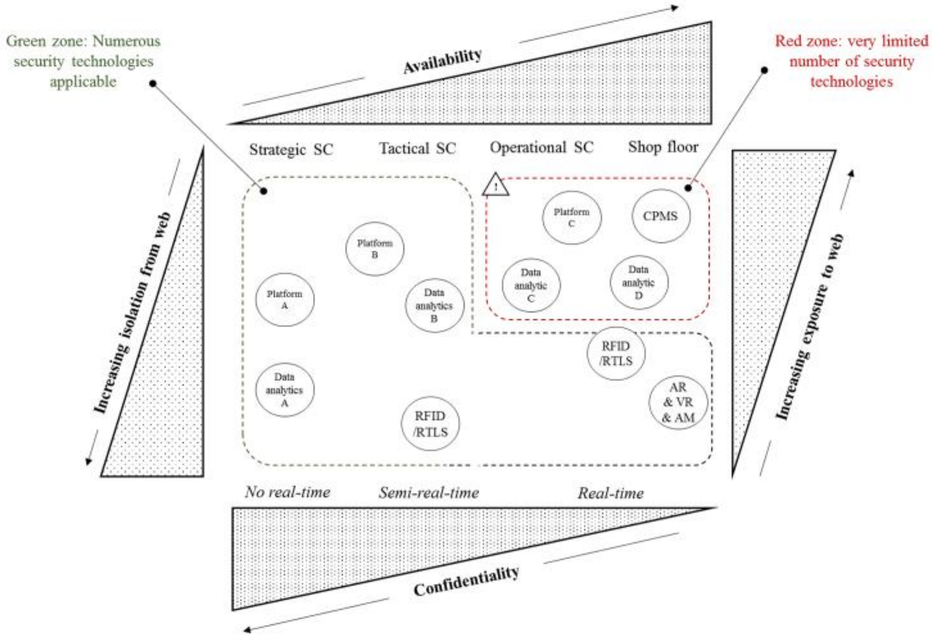

Figure 19: Green and red zone of security-technology application

Over the course of this paper, many possible technical solutions were analysed to counter this challenge. Three technical solutions are deemed fit:

a) *Separation of real-time controlling and semi-real-time monitoring unit, with firewall in-between*

   The monitoring-unit has no high-availability requirement and hence, can rely on various security-technologies. The controlling-unit has high-availability requirement and thus, is cut off from the public-domain and protected with firewall against monitoring-unit (CS8).

b) *Application white-listing*

   Only applications allowed by system-administrator can run on a system. This prevents Trojans to be activated as they are usually disguised as applications (CS3).

c) *Multiple-CPUs per application*

   This security-measure enables DTs to be updated (*'patched'*) even with availability-requirement of 24/7. DTs is supported by two alternate CPUs, which are patched if not in use (CS3).

It can be concluded that an increasing sophistication of the cyber-risk mitigation strategies is observable, yet appropriate strategies to cope with the requirement of high availability technologies are scarce. The three security measures listed above are an attempt to fill this gap and hence, to make DSCs more secure.

<u>Towards the development of cyber-resilient supply chains</u>

Based on the findings of the case studies, a framework for cyber-resilience in DSCs was developed and is presented in *Figure 20 - Figure 23*. This novel framework integrates approaches from supply chain configuration, supply chain risk management, digital technologies and cyber-risks. It can be used by academics and practitioners alike to systematically identify, assess and mitigate cyber risks in DSCs and hence, can be considered as a *'guide towards the development of cyber-resilient supply chains'*.

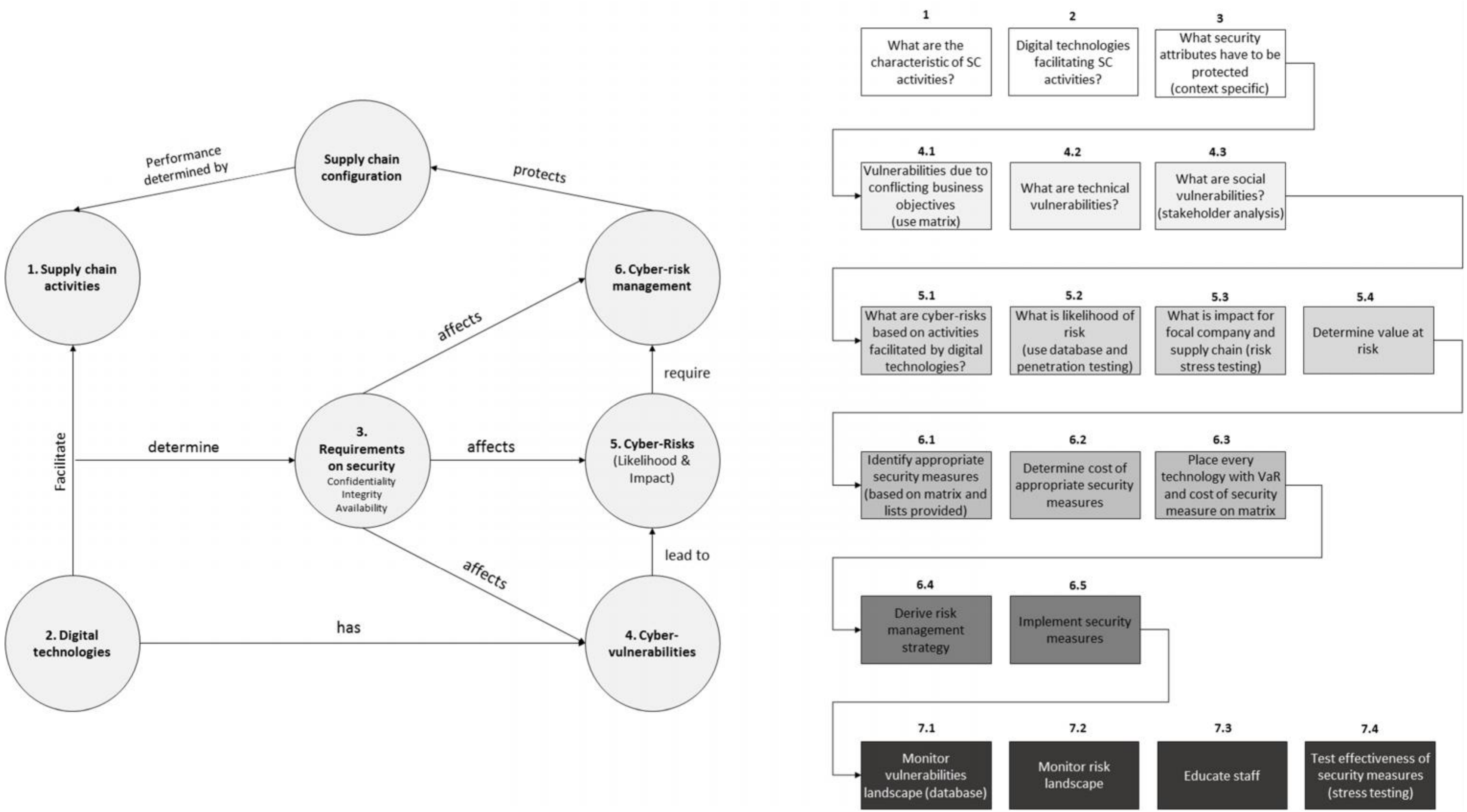

Figure 20: Summary: Cyber-resilience of digital supply chains - framework (I)

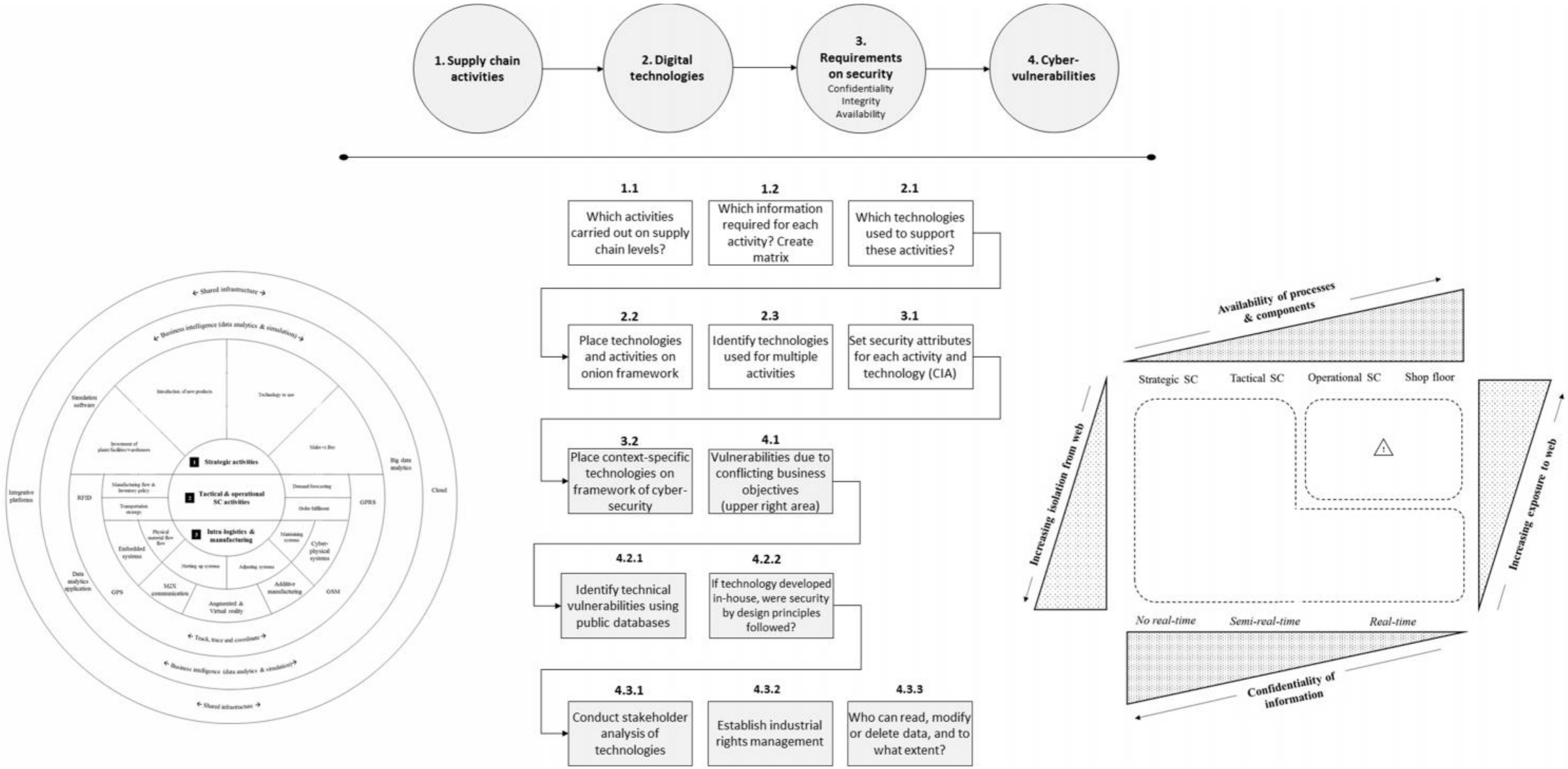

Figure 21: Cyber-resilience of digital supply chains - framework (II)

Figure 22: Cyber-resilience of digital supply chains - framework (III)

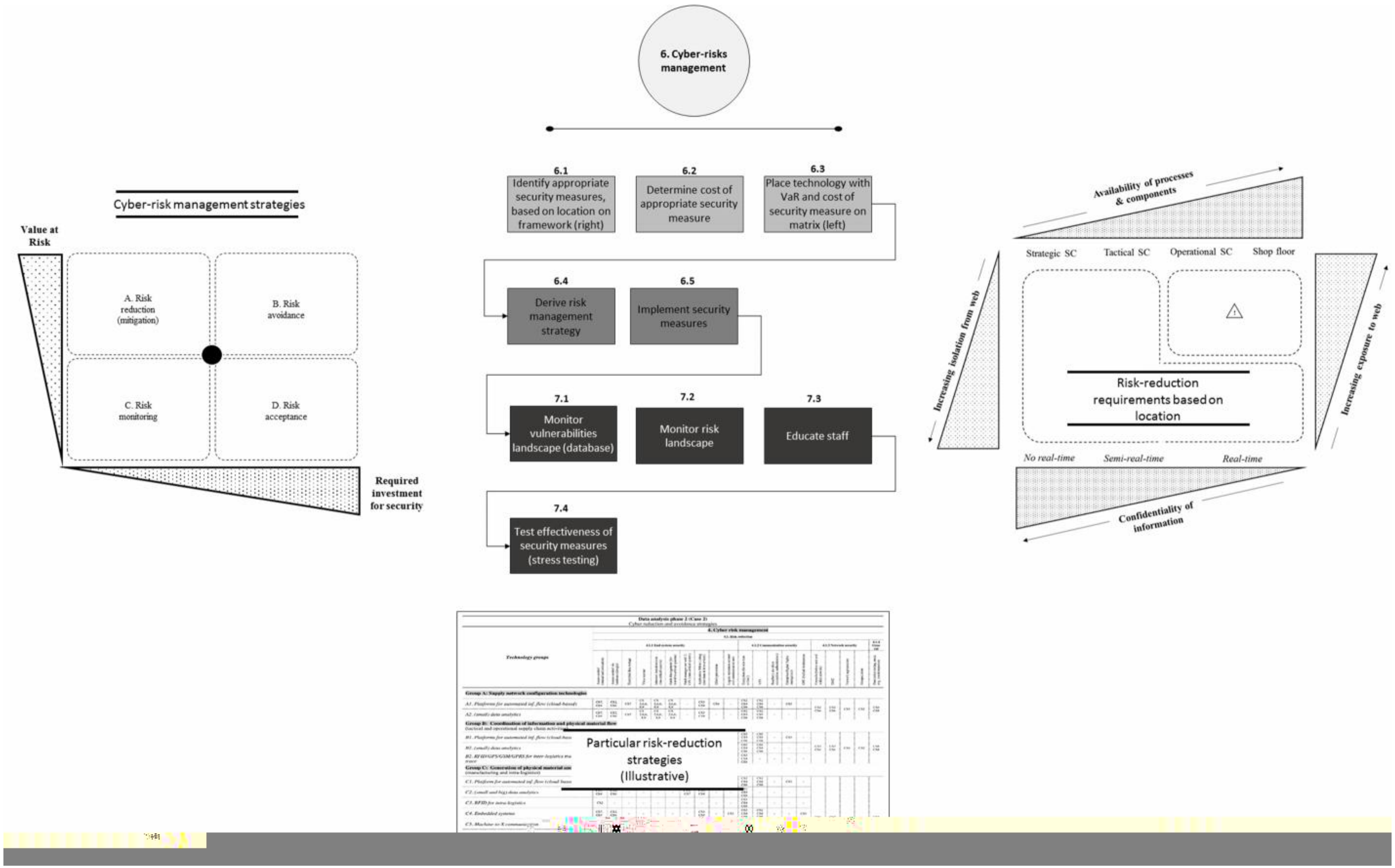

Figure 23: Cyber-resilience of digital supply chains - framework (IV

Conclusion

To conclude this paper, the brief background of the study will be summarised, key findings provided, limitations discussed and suggestions for further research proposed.

The purpose of this paper was to develop a conceptual cyber-resilience framework for digital supply chains. Extant literature in supply chain, -risk management, digital technologies and cyber-risks was reviewed to set the theoretical foundations and develop a conceptual framework. Various research strategies and methods were then studied to identify the most suitable approach for the research question. Case studies were deemed fit. Appropriate selection criteria were then defined and thorough market analysis conducted to select the adequate country, industries and firms for data collection. This data was analysed to capture key cyber-vulnerabilities, cyber-risks and mitigation strategies associated with vital supply chain activities. Based on the findings, a cyber-resilience framework was proposed to answer the following research question:

'How to identify and mitigate cyber-risks in the context of digital supply chains'

This section highlights key findings of this paper project, discusses implications for theory and practice, draws attention to limitations and suggests further research.

<u>*Key findings*</u>

To address cyber-vulnerabilities, cyber-risks and cyber-risk mitigation strategies of the DTs identified in the literature, their context has to be established. The context determines the security-attributes to protect (confidentiality, integrity or availability - CIA). It was found that those technologies with high availability-requirement and high exposure to the public-web, require particular attention with regards to the security-technologies applicable. Comparison to literature reveals that CIA-triad is studied extensively, however, it lacks application on industry examples. Hence, literature falls short to identify the implications of high-availability and high-exposure to web-technologies on applicable security-measures.

To address the cyber-vulnerabilities associated with the DTs described above, an updated categorisation was introduced: *'technical vulnerabilities'* (software error due to wrong development, software error adopted from vendor-application, poor access control, loosely encrypted databases, outdated systems) and *'social vulnerabilities'* (poor password, disobey to guidelines). It was found that among the technical vulnerabilities, *'outdated systems'* only refer to DTs with high availability-requirement. Existing research has not categorised and identified bespoke vulnerabilities of DTs in context of DSCs. This is due to the immaturity of *'cyber-risk in supply chain'*-literature.

Also, a novel framework was developed to support the identification highly-vulnerable DTs (see *Figure 15*).

The cyber-vulnerabilities described above lead to cyber-risks, which are categorised into four groups: sensitive data breaches risks, disruption/delay of material flow risks, compromised digital lifecycle risks and safety risks. These cyber-risks can be linked with supply-chain risks (see *Figure 18*). Comparison to literature reveals that this risk-classification was neither studied in cyber-security literature nor in supply-chain-risk literature. The former lacks implications of cyber-risks to supply-chains, the latter falls short on cyber-risks as cause of supply-chain risk.

Also, a novel framework was developed to infer categories of cyber-risks based on the security-attributes and exposure to public-web of DTs (see *Figure 16*).

Cyber-risks depicted above require cyber-risk mitigation strategies, which can be categorised into end-system security, communication-security, network-security and general-security. A framework was developed (see *Figure 19*) to categorise DTs into two different groups, from a security-technology point of view: DTs with numerous applicable security-technologies and DTs with limited applicable security-technologies. For the latter group, the three novel security-technologies identified were: application-whitelisting, redundant-CPUs and separation of controlling- and monitoring unit. Comparison to literature demonstrates that research lacks to recognise importance of security-attribute *'availability'* and hence, falls short to suggest mitigation strategies for DTs with high-availability requirement.

To contribute to the development of cyber-resilient supply chains, a cyber-resilience framework was developed (see *Figure 20-Figure 23*). It combines theories of supply chain configuration, supply chain risks, digital technologies and cyber-security. In its shorter version it comprises of 19 steps while the extended version comprises of 36 steps. Furthermore, it incorporates various frameworks developed during the course of this project. Comparison to literature reveals that this resilience-framework is a novel and multi-disciplinary approach to theory. Not a single paper was found to incorporate the phenomenon of cyber-risks in supply-chain-risk-management frameworks.

It can be concluded, that this paper indeed provided valuable contributions to theory.

Implications for theory

With regards to contributions to theory, knowledge was mostly provided or provided based on identified research-gaps.

B. Cyber-resilience in DSCs	
Conflicting CIA-security-attributes of DTs in DSCs	**Provided (with framework)**
Identification and categorisation of vulnerabilities of DTs in DSCs	**Provided (with framework)**
Identification and categorisation of cyber-risks of DTs in DSCs	**Provided (with framework)**
Suggestion of mitigation strategies for DTs in DSCs	**Provided (with framework)**
Cyber-resilience framework for DSCs	**Provided (with framework)**

Figure 24: Contribution to research

Implications for practice

This paper provides practitioners a 'guide' to cope with one of the greatest challenges in DSC: cyber-risks. The framework developed provides a starting point of how to characterise a DSC from a technology point of view, combining theories of SC configuration and decision-making, supply chain - and cyber-risks.

Essentially, this paper provides a first step towards the development of cyber-resilient supply chains.

Limitations

Due to confidentiality reasons, difficulties in obtaining the relevant data and time constraints, cyber-risk assessment could not be fully investigated. Also, some of the organisations involved in the data collection for cyber-risks were multi-national corporations. However, small- and medium sized companies are also integral part of many supply chains, but cannot afford establishment of dedicated cyber-security divisions. Their perspective is lacking in this paper.

<u>Suggestion for further research</u>

Suggestion for further research can be concluded from the tables below.

	Suggestion for further research (Digital supply chains)	
	Area	*Need for research*
	Digital supply chains	
Technology maturity	*Maturity of digital technologies to increase performance of supply chain activities*	• More research should be conducted into assessing the maturity of digital technologies suggested for DSCs • For example, big data analytics is considered to be a mature technology among software developers. However, concerns regarding the maturity of this technique for specific SC activities remains unanswered. • Suggested research methodology: Case studies comprising software developers and industry
Network configuration	*Comparing the level of digital technology deployment at different stages of the supply chain*	• Research investigating the different levels of digital technology deployment at companies further downstream with companies further upstream the supply chain • Questions with regards to the different requirements these companies have could provide insight into varying needs of digital technologies • Suggested research methodology: Case studies comprising three types of companies: Raw material manufacturer, component manufacturer and original equipment manufacturer
	Digital supply chains involving countries from developing countries	• Most supply chains involve companies located in developed countries (e.g. Germany) and developing countries (e.g. India, China) • Research delving into the requirements in terms of infrastructure, human capital, equipment etc. a firm and country must meet in order to be part of a digital supply chain, will become crucial. • Only if supply chain partners are collectively capable of implementing digital technologies, the entire supply chain will benefit • Suggested methodology: Case studies involving supply chain partners from developed developing country
Governance	*Justifiable distribution of costs along supply chain partners associated with implementation of digital technologies*	• Mostly, supply chain partners implement digital technologies collaboratively • Research investigating techniques as to how the costs can be spread across supply chain partners – if entire supply chain is benefiting – should be carried out • This gap is one of the biggest factors slowing down the transformation into digital supply chains • Suggested research methodology: Case studies involving three supply chain partners • Divisions involved: Supply chain management related divisions, information technology and internal accounting
	Legal governance of digital supply chains	• As supply chains become digital, the boundaries between firms become blur • Consequently, new forms of legal collaboration will be important, particularly concerning 'ownership of data' • This issue was also found to be one of the barriers in digital collaboration • How supply chain partners overcome these challenges from a legal point of view, must be tackled • Suggested methodology: Case studies involving industry and legal organisations

Figure 25: Further research on digital supply chains

	Suggestion for further research (Cyber-resilience)	
	Area	*Need for research*
	Cyber-resilience in DSCs	
	Testing of cyber-resilience framework	• The framework developed should be tested • This would help to validate or modify it • Suggested methodology: In-depth case study with SME division (small-scale to test every aspect)
Vulnerability (technological, organisational, structural)	*Potential cyber attackers and incentives*	• Cyber-risks are triggered by potential cyber-attackers • Characterising likely attackers of an organisation, along with their incentives, is vital for security in supply chains • Studies identifying potential attacker types and incentives are lacking • Suggested methodology: In-depth case study with company developing high intellectual property products
	Common language	• During this research project it was found that a common language among security experts on one hand, and industrialists on the other hand is lacking • This lack of communication leads to a dangerous unawareness of cyber-risks among industrialists • Studies identifying the factors which could resolve this communication gap should be carried out
	Cyber-vulnerabilities due to SME involvement	• Small and medium-sized companies (SMEs) are integral part of every supply chain • However, establishment of dedicated cyber-security not affordable for SMEs • Hence, SMEs considered to be 'weakest link in the chain' with respect to security • How can a knowledge transfer among SC be initiated, and how can government support these SMEs with respect to security
Cyber-risk assessment	*Cyber-risks likelihood*	• This area is considered to be one of the most challenging areas in cyber-security • A systematic approach of how to assess the likelihood of an attack, as, is missing for digital supply chains • Difficult to assess due to the different levels of technical and social vulnerabilities. Furthermore, depends on attacker's capabilities and incentives (see further research above) • Suggested methodology: In-depth case study, involving company (industry preferably with high intellectual property, division preferably R&D) and cyber-security expert company. However, this has to be carried out highly confidential.
Cyber-resilience	*Cyber-risk mitigation strategies*	• During the course of this research, three different types of mitigation strategies were suggested for technologies with high availability requirement and high exposure to public-web • These security measures should be validated • Suggested methodology: Case-studies involving company from industry (preferably SME) and cyber-security firm

Figure 26: Further research on cyber-resilience of supply chains

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Transfer Activities of Lean Management to Other Industries
-Transplanting Heijunka Concept for Leanised Operations-

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Abstract: Lean management, its concept, approach and technology, has been transferred among factories, business functions for these decades and, as recent trend, among industries. This paper discusses some cases on inter-industry transfer activities of lean management especially focusing on Heijunka operations, which is one of the most important value senses or concepts in lean. Two significant examples are introduced for confirming its versatility, i.e. management for stabilised electricity power supply in smart grid systems and stabilised production/supply of agricultural-products. These activities could accentuate the relevance of lean management.

Topic: Lean Production and Smart Cities
Keywords: Lean management, Operations and production management, Supply chain, Heijunka (Level Production/Supply), Muri, Mura, Muda, Smart Grid, Electric Power Supply, Agri-businesses, Performance evaluation

1. Introduction

For these decades, substantial efforts on transferring lean management have been made by industrial professionals over the world. Figure 1 to 3 illustrates categories of these activities. First category is special transfer including that from domestic factories to offshore factories, among offshore factories within the same countries and among countries.

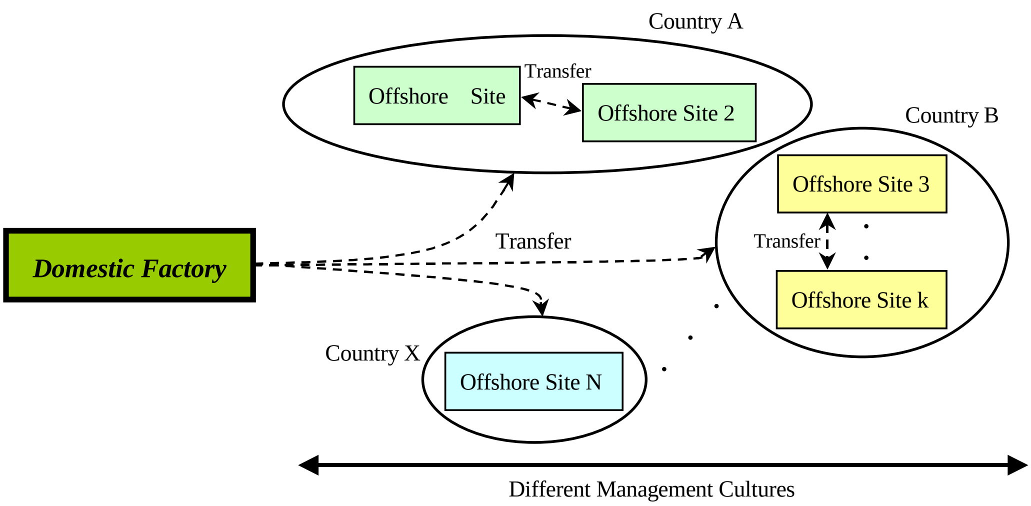

Figure 1. Various patterns of special transfer of lean management (Katayama, H.; 2014b)

Second category is functional transfer including that from manufacturing sites to other business functions such as R & D, system design and operations preparatory divisions, sales, supply, delivery and furthermore, inter- transfer among these functions.

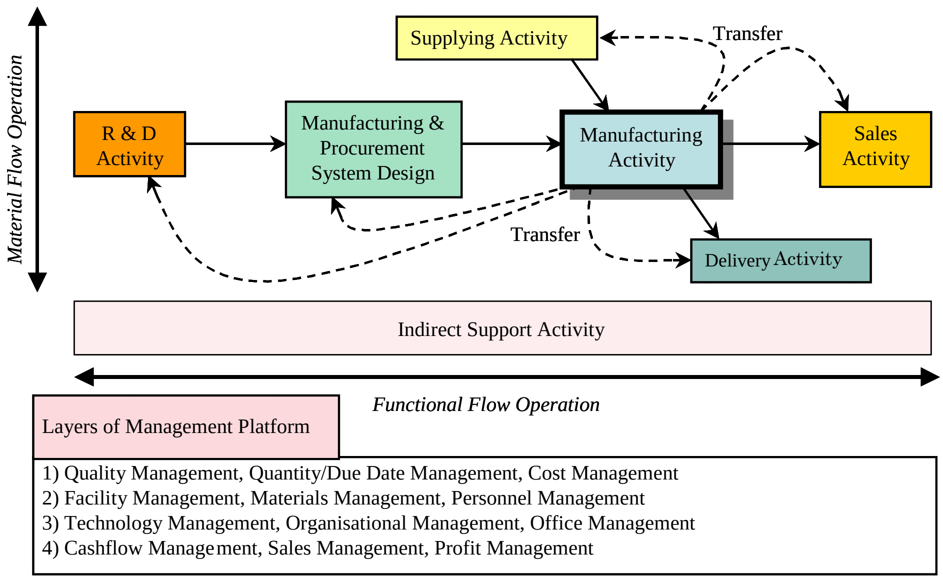

Figure 2. Various patterns of functional transfer of lean management (Katayama, H.; 2014b)

Third category is inter-industry transfer including from manufacturing industry to other industries such as medical industries, transportation industries, public services and furthermore, inter-transfer among these industries.

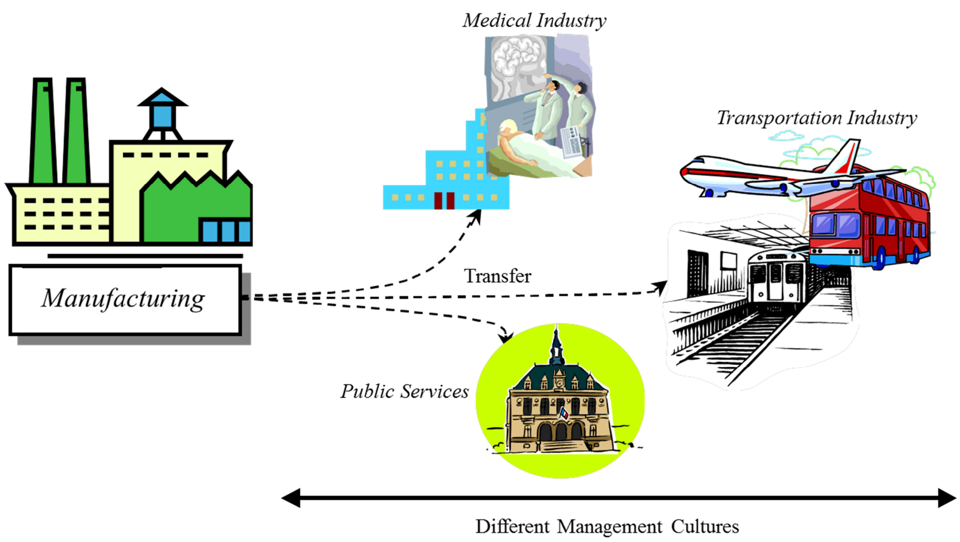

Figure 3. Various patterns of inter-industry transfer of lean management (Katayama, H.; 2014b)

2. Transfer issues of lean management

There are various contents having to transfer which includes way of thinking and/or sense of value, organisational driving force, technological issues, way of human resource development etc., and in this paper, the first and second issues are briefly discussed followed by the third issue as the main portion. Regarding to the first issue, the way of thinking and/or sense of value, "contradiction-driven thinking" must be the distinctive item. It starts by setting the mission impossible and/or difficult, namely contradiction setting, then, think and launch effective actions on the PDCA platform to close to the mission as much as possible. This is the compulsory issue to share among people in an organisation. Therefore its transferability must be reinforced through human resource development activities. There is a procedure eliminating so-called Muri (Strained), Mura (Variegated) and Muda (Wasted) behind this concept, which was handed down by Japanese industrial tradition. Essence of this procedure is visualising these phenomena and then trying to zerotise them by this order. Again it is a contradictory target.

There are some example technologies linking with this concept and two distinctive technologies from TPS (Toyota Production System) and TPM (Total Productive Maintenance and Management) schemes are described below **(**Katayama, H.; 2015).

Example 1: KANBAN System (a TPS tool)

Here, the number of Kanban plays the important role, as it can visualise the weak operative functions in supply chain by suppressing this number one by one. This process is considered as contradiction setting as it intends to make failure. It happens because smaller the number of Kanban, then tighter on time supply. Once bottleneck operations are revealed, countermeasures must be examined to overcome the weakness. That is, firstly Muri is forced, then Mura and Muda are extracted and these are intended to zerotise by this order, which are contradictory targets. The reason of Mura first is that it, in other word fluctuation, tends to hide where and how big Muda exists.

Example 2: 4M Analysis and Standardisation (a TPM tool)

4M means Man, Machine, Material and Method, which are the major contributers of operational performance. Therefore, fluctuation of these values closely link with instability of outcome values as well as system variables. To investigate the relation between resources and outcomes, level of each 4M resources issues are modified as tight as possible, i.e. contradiction setting, then examine to seek the proper level of resources that guarantees zero fluctuation of outcome values, i.e. contradictory target. DOE (Design of Experiment) is often implemented for this investigation process.

Regarding to the second issue, namely organisational driving force, there are number of relevant lean schemes developed under Japanese manufacturing scene. Some of these are given below **(**Katayama, H.; 2015).

1) TQM (Total Quality Management)
2) TPM
3) TP Management (Total Productivity Management)
4) Hoshin Kanri (Policy Deployment Process)
5) Various in-house performance improvement schemes developed by leading companies such as TPS

Each scheme has its own concrete structure. For instance, feature of TPM scheme consisting of five issues is given below.

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

As this scheme was constructed in terms of general format, it provides wide range of applicability such as from car industry to food industry and multi-national companies to local SMEs. Therefore, its transferability is also quite high.

Regarding to the third issue, that is technological issues, Mura related management tool is focused to discuss in the next chapter, as its elimination is very critical and compulsory for Muda reduction, both of which bring us to strong leanised organisation.

3. Cases of technological transfer to other industries

As mentioned in the previous chapter, Mura is variegated phenomena of system variables including input and output. The concept to eliminate this phenomenon in lean context is called Heijunka (level production/supply).

3.1. A case of energy industry

In this section, recent research contribution from author's laboratory on lean management application to smart grid management is introduced (Takeyama, K. et al.; 2016). Incentive of this work is obtaining the critical knowledge for designing and managing stable and lossless systems. Outline of the contents is given as follows.

1) Study Procedure

Step 1: Estimation of produced energy

Getting the amount of solar radiation, produced electricity energy of each household in the grid is estimated through developed solar panel model.

Step 2: Estimation of electricity demand

Electricity demand of each household in the grid is estimated through established demand statistical model.

Step 3: Examination and implementation of EV-equipped storage battery model

Examining the charge/discharge mechanism of EV-equipped battery, a performance model of such battery is established.

Step 4: Simulation and discussion

Performing simulation analysis, trade-off relation between disposed electricity energy and that of shortage is figured out for discussion.

2) Detail of Each Step

<Step 1> Estimation of produced energy

During time period *t*, household *i*'s energy production can be calculated by equation (1) which is referred from Murata et al. model (Murata, K. et al.; 2015). Where, amount of solar radiation can be referred from NEDO's homepage, a subsidised organisation of Japanese government.

$$sp_{ih} = \max\left\{0, \min\left(\varepsilon_h^c \int_h^{h+\Delta} \gamma \frac{p_t}{3.6} dt \times s_i,\ p_{\max} \times s_i\right)\right\} \quad (1)$$

<Symbols>

sp_{ih}: House i's energy production (time t)

ε_h^c: Solar energy panel power coefficient according to temperature C (time t)

γ: Solar energy panel's energy conversion ratio

p_t: Solar radiation intensity (time t)

s_i : Number of panels on house i

$p_{\max}$: Panel power by area

<Step 2> Estimation of electricity demand

Each household's electricity demand is depending on the type and pattern of daily electricity usage within each house, however, the average electricity usage of householders in Japan can be referred from the statistics of METI (Ministry of Economy, Trade, and Industry) of Japan. Then, data of electricity demand for simulation analysis can be generated by using random numbers based on actual average and variance data of householders. In addition, each EV's electricity usage, when running the EV, is calculated through average driving distance of cars owned by standard household multiplied by the amount of electricity being used for running such distance.

<Step 3> Examination and implementation of EV-equipped storage battery model

The sum of electricity within storage batteries in a smart grid system can be calculated by equations (2) and (3) which are modified version of Murata et al. model (Murata, K. et al.; 2015). This study particularly emphasises on the standby percentage α of EV, which represents the number of cars that are parked at home and ready to use their storage batteries.

$$ep_h = \left(\sum_{i=1}^{n} sp_{ih} - \sum_{i=1}^{n} cp_{ih}\right) \times \mu_p - \alpha\mu_{out} \times \sum_{i=1}^{n} vp_{ih} \quad (2)$$

$$\mu_p = \begin{cases} \mu_{in} & (\text{charge} \quad \sum_{i=1}^{n} sp_{ih} - \sum_{i=1}^{n} cp_{ih} \geq 0) \\ \mu_{out} & (\text{discharge} \quad \sum_{i=1}^{n} sp_{ih} - \sum_{i=1}^{n} cp_{ih} < 0) \end{cases} \quad (3)$$

<Symbols>

ep_h : Amount of electricity in storage battery (time t)

sp_{ih}: House i's energy production (time t)

cp_{ih}: House i's electricity demand (time t) Note: Does not include EV's electricity demand

vp_{ih}: House i's car's electricity demand

μ_{in}, μ_{out} : Storage battery's energy conversion ratio (charge and discharge)

α: EV's standby percentage in the grid

3) Simulation and Discussion <Step 4>

(a) Simulation Conditions

In the experimental examination, following conditions are supposed.

① Solar panel's energy conversion rate: 0.21

② Positioning of solar panel: Azimuth; 0 degree, Radiation Angle; 30 degree

③ Battery: Specification; nickel ion battery, Capacity; 244KWh, Energy conversion ratio; 0.9 both charge and discharge

④ Number of EVs per household: 1

(b) Notable results

Figure 4 shows sample paths of generated electricity energy under the condition of infinite battery capacity with α=0.5 and 30 householders in the grid. Note that horizontal line at created electricity energy level=200 is drawn for comparison with the case of capacity =200 KWh. It is noticed that besides of the cases of the number of panels between 18 and 19 are strongly diversified, namely from Mura point of view, these cases must not be adopted. On the contrary, especially the case of 18.7 panels can be delicate but well configured from Heijunka energy supply point of view. This fact is quite important knowledge for designing grid systems that must provide reliable lifeline. Different configuration can be also examined by tuning parameters under the proposed model.

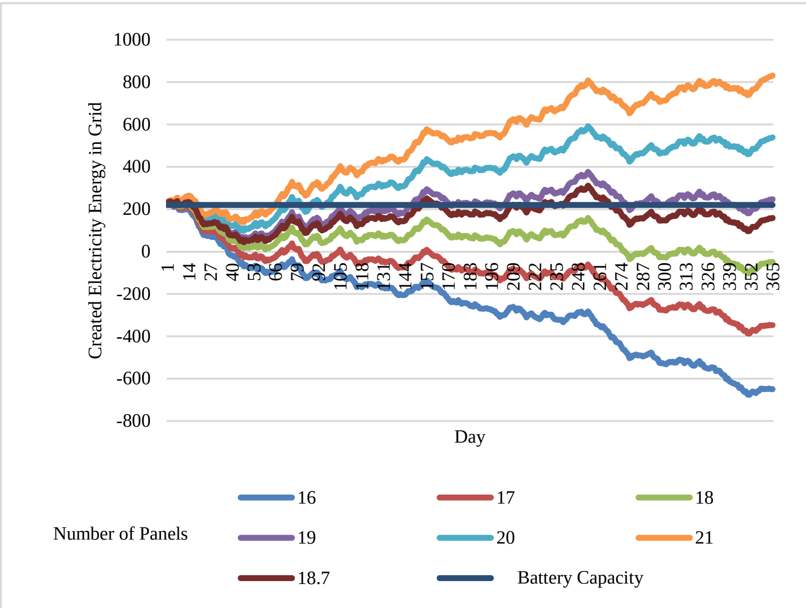

Figure 4. Trends of generated electricity energy

(Battery Capacity: Infinite, α=0.5, Number of Household: 30)

Figure 5 illustrates characteristics of disposed electricity energy along with days in case of battery capacity =200KWh. From this result, in case of number of panels is 21, for example, battery capacity is too small to utilise produced electricity effectively. On the contrary, it can be also noticed that panel investment is unnecessarily big for payable configuration. This means careful parameter tuning is quite important for leanised design of electricity supply systems.

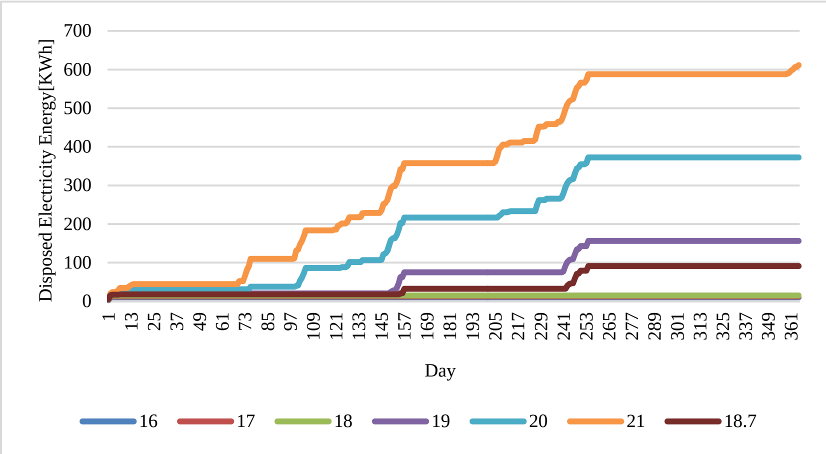

Figure 5. Trends of Disposed Electricity Energy
(Battery Capacity: 200KWh, α=0.5, Number of Household: 30)

Figure 6 shows the trade-off relation between cumulative disposed electricity energy and electricity energy shortage over the years. Horizontal axis represents inefficiency level of energy usage and vertical axis is of risk level. It can be immediately noticed that amount of produced energy must be automatically disposed by reducing risk of electricity shortage and this risk cannot be disregarded when energy disposal is improved.

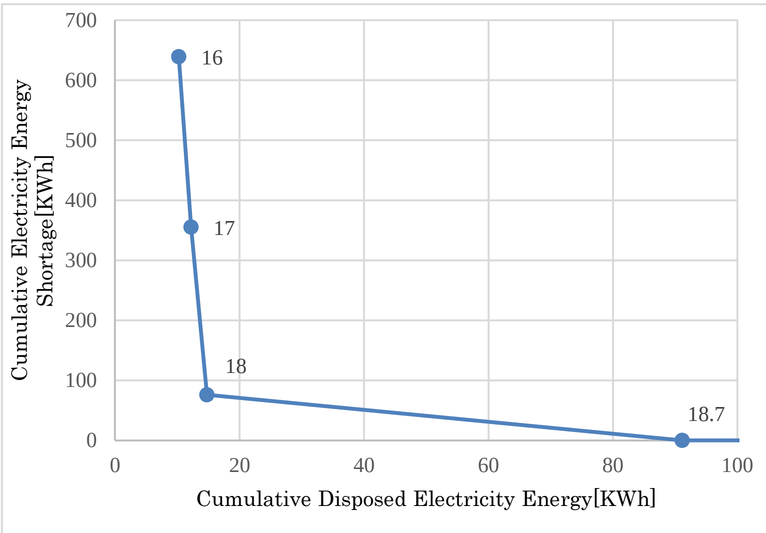

Figure 6. Trade-off Characteristics between Cumulative Disposed Electricity Energy and Cumulative Electricity Energy Shortage
(Battery Capacity: 200KWh, α=0.5, Number of Household: 30)

For further improvement of the system, it must be necessary to develop highly performed panels and batteries with relevant management contrivance for breaking through the obtained trade-off wall under uncertain natural environment.

3.2. A case of agricultural industry

In this section, topic on lean management application to agricultural industry is discussed (Katayama, H. et al.; 2016). Incentive of this research topic is again obtaining the critical knowledge for designing and managing stable and lossless production and supply system for agri-products. Outline of the contents is given as follows.

1) Background

Based on the rapidly growing market of edible leaf products in Japan, especially among people who desire healthy foods, many SME farmers are getting into this category of business. Then, competitiveness in this sector became serious. Expected global agreements such as TPP also pursue this trend. Moreover, looking at the history of this industry, due to many turbulent factors in the production process, lack of human resources and useful tools/weapons relevant for farms' management are still getting worse. Recognising this situation, this study intends to contribute to develop leanised organisation especially focuses on realising Heijunka operations. Figure 7 illustrates the process which consists of four major sub-processes, namely seeding, germination, harvesting and shipping. Each sub-process has unidentified mechanisms creating losses such as germination yield rate, harvest yield rate and sorting yield rate.

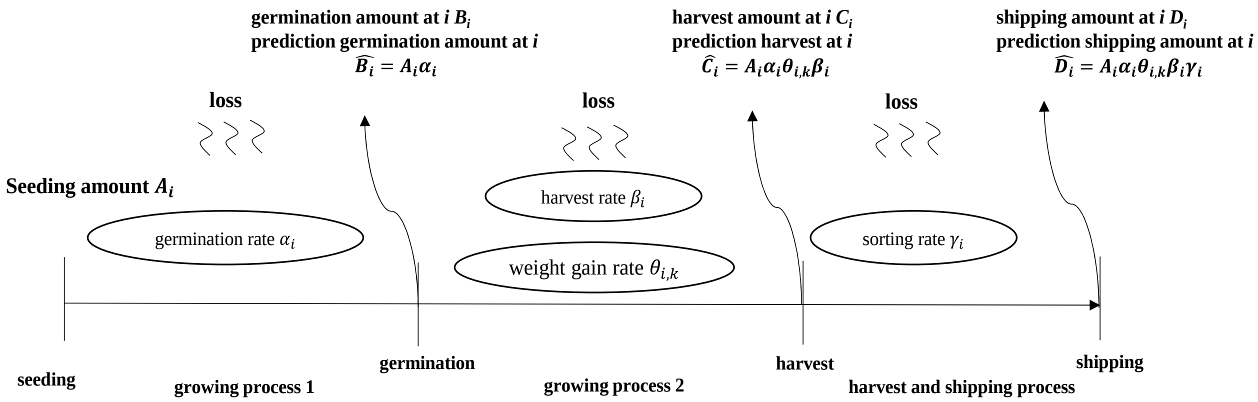

Figure 7: Outline of the production process of the case company

2) Study Procedure

Following 3-step approach is adopted to cope with the problem.

Step 1: Data collection

The data of major leaf products is collected and sorted for model building.

Period to investigate: recent 3 year terms

Data items: quantity of seeding, harvest and shipment

Step 2: Development of parameter estimation procedure

Symbols described in Figure 7 are summarised in Table 1.

The estimated values δ, θ_k and γ, which are the mean of population parameter δ_i ,$\theta_{k,\,i}$, γ_i (See Table 1), are defined as $\hat{\delta}, \hat{\theta}_k, \hat{\gamma}$ respectively, and these statistics are evaluated by the equations described in the following steps. In addition, because of that δ and γ fluctuate in every seeding operation, standard deviations of these parameters are also estimated for effective production management.

Table 1. Symbols used in the system representation

A_i	:Seeding quantity at term *i* [kg/a]	α_i	: Germination yield rate at term *i*
C_i	: Harvest quantity at term *i* [kg/a]	β_i	: Harvest yield rate at term *i*
$\hat{C}_i$	: Estimated harvest at term *i* [kg/a]	γ_i	: Sorting yield rate at term *i*
D_i	: Shipping quantity at term *i* [kg/a]	$\theta_{i,k}$	: Weight gain rate in *k* (*k*=1:summer,*k*=2:winter)
$\hat{D}_i$	: Estimated shipping quantity at term *i* [kg/a]	δ_i	: $\alpha_i \times \beta_i$
N	: period [day]		

Step 2-1-1: Calculation formulas of $\hat{\delta}$, $\hat{\theta}_k$

Estimates $\hat{\delta}$ and $\hat{\theta}_k$ can be evaluated by ordinary least square method through minimising the total difference between actual data of harvest and its estimated quantity as shown in Formulas (4)-(7).

Where, based on concerned manager's long-term experience, population parameters δ and θ_k, which denote the product of germination yield rate and harvest yield rate, and weight gain rate, are supposed to satisfy conditions (6) and (7) respectively.

$$\min \sum_{i \in N} (\hat{C}_i - C_i)^2 \tag{4}$$

$$\hat{C}_i = A_i \times \hat{\delta} \times \hat{\theta}_k \ (k = 1,2) \tag{5}$$

$$s.t.\ 0.64 \le \delta \le 1 \tag{6}$$

$$100 \le \theta_{i,k} \le 300 \tag{7}$$

Step 2-1-2: Calculation formulas of standard derivation

Estimating standard derivation of $\hat{\delta}$ is also important as this value represents the degree of internal turbulence that harms stable production.

$$\sigma_{\hat{\delta}} = S(\hat{\delta}) \tag{8}$$

Where, sample data of $\hat{\delta}$ is obtained by the formula $\hat{\delta}_i = \frac{C_i}{A_i \hat{\theta}_k}$, which is deduced from formula (5) and *S* is the operator for standard deviation.

Step 2-2-1: Calculation formula of $\hat{\gamma}$

Point estimate of sorting rate $\hat{\gamma}$ can be obtained by the quotient of actual data of shipment and harvest quantities as shown in formula (9). Where, *E* is the operator for mean value.

$$E(\hat{\gamma}) = E\left(\frac{D_i}{C_i}\right) \tag{9}$$

Step 2-2-2: Calculation formula of standard derivation

As the same meaning described in Step 2-1-2, standard derivation of $\hat{\gamma}$ is also important to estimate.

$$\sigma_{\hat{\gamma}} = S(\hat{\gamma}) = S(\frac{D_i}{C_i}) \quad (10)$$

Step 3: Model of level control of harvest quantity

Firstly, let's clarify the relationship between total seeding quantity (input) and harvest quantity (output) as it is not possible to design proper level-production plan without such information.

The formula representing the relation between seeding interval and harvest quantity is given in Formula (11). Where, seeding interval is also fluctuated due to lack of workers, unstable schedule of using farm field etc. By using Formula (5) given in Step 2-1-1, interaction of expected seeding quantity and harvest quantity is obtained in (12)

$$R_k = \frac{Q}{E(x_i)} \times E(\hat{C}_i) \quad (11)$$

$$\hat{C}_i = A_i \times \hat{\delta} \times \hat{\theta}_k \ (k = 1,2) \quad (5)$$

$$E(A_i) = \frac{R_k}{Q} \times \frac{1}{\hat{\delta}\hat{\theta}_k} E(x_i) \quad (12)$$

<Symbols>

R_k	: Total harvest quantity in k [kg/a] (k=1:summer, k=2:winter)	A_i	: Seeding quantity at term i [kg/a]
Q	: Period (180days)	x_i	: Seeding interval at term i [days]
		C_i	: Harvest quantity at term i [kg/a]

Secondly, utilising this formulas and knowledge, standard derivation and average of variables must be controlled by this order to realize continuous and stable supply through level production principle. This procedure is illustrated in Figure 8.

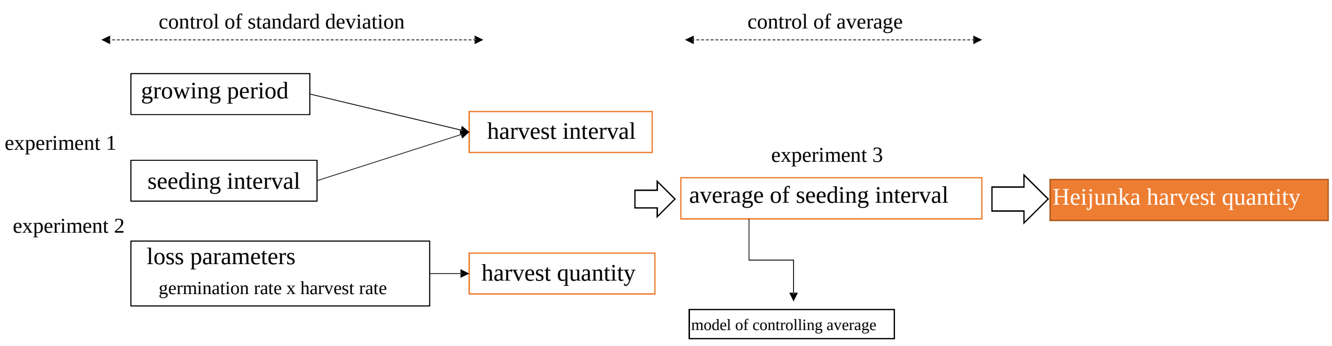

Figure 8. Model of level production (Heijunka operation)

As variables and parameters in this system is very volatile, stochastic simulation is a possible way to analyse the characteristics. Then, in the first stage, variance control must be focused, which consists of 2 experiments, *i.e.* causal analysis between growing period + seeding interval and harvest interval (experiment 1) and that of loss parameters $\delta(=\alpha \times \beta)$, γ, θ and harvest quantity (experiment 2). In the second stage, average control can be followed and level production and supply operations become much easier than before, because internal turbulence caused by fluctuated variables and parameters were controlled in the first stage.

3) Result and Discussion

In this section, three results derived from the model/procedure described in the previous section are summarised.

(a) Result of parameter estimation of Step 2 in Section 2)

The result of estimated parameters of target product is shown in Table 2.

Table 2. Estimated parameters of “Beat” production

(Data: summer: 96 days/ winter: 61 days)

	$\hat{\delta}$	$\hat{\theta}_1$	$\hat{\theta}_2$	$\hat{\gamma}$
average	0.74	100.0	146.0	0.57
standard deviation	0.24	-	-	0.21

From this result, it is noticed that average of $\hat{\gamma}$ (Sorting yield rate) is smaller than $\hat{\delta}$ (Germination yield rate x Harvest yield rate) and both of the standard derivation are roughly equal. Therefore, first priority for raising productivity must be improvement of $\hat{\gamma}$ (Sorting yield rate), which may be tackled by industrial engineering methods.

(b) Result of levelling control model from Step 3 in Section2)

Outline of each investigation is summarized below and detail characteristics are given in Table 3, where result of the experiment derived the most significant performance is described, that is on Experiment 3.

<Result of Experiment 3>

Purpose: Realization of frequent small-lot production (Level production)

Table 3. Result of Experiment 3

Case 1	Seeding quantity	Seeding interval	Growing period	Harvest interval	Harvest quantity [kg/a]
average	0.88	4.09	63.07	4.14	71.12
standard deviation	0.00	2.23	18.98	4.03	6.46

Case 2	Seeding quantity	Seeding interval	Growing period	Harvest interval	Harvest quantity [kg/a]
average	0.87	4.06	63.73	4.11	71.80
standard deviation	0.00	1.50	11.46	3.69	5.41

Case 3	Seeding quantity	Seeding interval	Growing period	Harvest interval	Harvest quantity [kg/a]
average	0.86	4.04	64.06	4.02	70.07
standard deviation	0.00	0.74	6.07	3.42	5.30

Case 4	Seeding quantity	Seeding interval	Growing period	Harvest interval	Harvest quantity [kg/a]
average	0.86	4.00	64.00	4.00	69.96
standard deviation	0.00	0.00	0.00	0.00	5.17

Where,

Variable Conditions: Seeding quantity ⇨ average 0.9 (reduced), SD 0.0 (fixed)

	Seeding interval	⇨ average 4	(reduced),	SD 2.23- 0.0	(reduced)
	Growing period	⇨ average 64	(fixed),	SD 19-0.0	(reduced)
Parameter Conditions:	all parameters	⇨ average (See Table 1)		SD 0.05	(fixed)
Summary Result:	Harvest interval	⇨ average 4	(decreased),	SD 4.0-0.0	(decreased)
	Harvest quantity	⇨ average 70	(decreased),	SD 6.46-5.17	(decreased)

Remarks: Reduction of average with frequency increase is right way for level production which is composed by reducing average seeding quantity and its interval together. As a result, harvest interval and quantity are both decreased. In addition, turbulent level of the entire system is not notable as proper countermeasure must be performed beforehand.

4. Concluding Remarks

This paper discussed on inter-industry transfer of lean management especially focusing on Heijunka technology, which is one of the most important value senses or concepts in lean. Two example systems currently being paid attention such as electricity power supply system in smart grid and production/supply system of agricultural-products were taken up for discussion. Through model analyses of the objective systems utilising Heijunka technology and concept developed in manufacturing industry, its transferability and effectiveness were ensured.

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Convergence in health and medical technologies: the development of nascent value networks

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Abstract
New developments such as 'Precision Medicine' and 'Digital Health' are emerging as important areas in healthcare technology, underpinned by the concept of '*convergent*' or '*cross-industry'* innovation, resulting in greater uncertainty and influence from new knowledge and actors, including previously disparate technologies and capabilities. This brings specific challenges in the development of 'nascent value networks'.

This research aims, in the context of healthcare and medical technologies, to address gaps in understanding on *how organisations innovate in complex, highly dynamic convergent and emergent ecosystems, specifically how they form nascent value networks.*

We base our research on empirical analysis in longitudinal case studies. An exploratory phase involved a semi-structured interviews of ecosystem stakeholders, to provide context. The second phase involved case studies conducted over a 15 to 20-month period employing a combination of case interviews, field observations (e.g. meetings and workshops) and primary documents and supplementary evidence from public documents.

There has been limited empirical research to understand the innovation capabilities required in such nascent and convergent ecosystems, and specifically value network forming capabilities. We contribute to the relational capability literature concerning creation of nascent value networks and provide practical approaches for innovators in this field. More broadly we contribute to the convergent innovation literature.

Keywords: convergent innovation, ecosystems, value networks, relational capabilities

Introduction
Innovation in healthcare and medical technologies is recognised as critical to deliver better outcomes for patients and to control burgeoning costs (Christensen et al. 2009; Kim et al. 2013; Burns 2012). Increasingly innovators in healthcare seek to transfer knowledge and collaborate with partners from outside of the healthcare industry (Bernabo et al. 2009; Shmulewitz et al. 2006). Developments such as developments such as 'Precision Medicine', 'Regenerative Medicine' and 'Digital Health' result from collaborations across diverse industries (Sharp 2014).

In order to profit from such cross-industry collaborations, innovators must be able to find, and then transfer knowledge with their cross-industry partners (Zahra & George 2002; Gilsing &

Nooteboom 2006) and then create new organizational boundaries (Santos & Eisenhardt 2005) as they form value networks to deliver the innovations to customers (Harrington & Srai 2016). Much of the extant value network literature focuses on existing and established value networks (for examples see Choi & Hong 2002; Srai & Gregory 2008), identifying ways to optimise, control or govern these (Gereffi et al. 2005). There is limited literature on the formation of nascent and emerging value networks (Sebastiao & Golicic 2008).

Based upon five longitudinal cases, conducted in organizations operating in convergent innovation of healthcare technologies, within the UK, we conducted empirical research to analyse how these firms formed value networks in the nascent stages the life-cycle. This study reveals that alternative search and sense-making processes may be needed to help navigate the nascent field, and that negotiation with potential collaborators requires more than addressing technological and contractual complementarities, but requires actions and capabilities to create and demonstrate relational value and trust to foster those connections. As the venture evolves, activities to both nurture the innovation, the value network and the nascent ecosystem are required to address risks, uncertainties and a lack of infrastructure support common in nascent ecosystems. Based upon our findings we contribute to the current literature on nascent and emerging value networks and the management of convergent innovation.

Theoretical Framework

Innovation across industry boundaries

Innovation has been the focus of extensive research (Fagerberg et al. 2012) with much of that focus being on the innovation system or on organizing innovation. Montoya-Weiss (1994) and Holahan (2014) identified 'best practices'; the emphasis being in organizing innovation. However, much of this literature has focussed on innovation by incumbents in existing industries. More recently there has increasing interest in 'cross-industry' or 'convergent' innovation (Brunswicker & Hutschek 2010; Enkel & Gassmann 2010; Gassmann et al. 2010), and importantly, many major healthcare developments such as 'Precision Medicine', 'Regenerative Medicine' and 'Digital Health' are underpinned by convergence, using technologies and capabilities from diverse industries (Sharp 2014). However, convergence can result in higher levels of uncertainty and risk as the diverse technology, partners and ecosystems merge (Hacklin & Wallin 2013; Rikkiev & Mäkinen 2013). Both technological and complementary capabilities potentially affect a firm's entry and entry mode in new fields (Anand et al. 2010). The influence of strategic partners (as part of the emerging value network), on innovation, has also been shown to be an important factor (Bröring & Leker 2007). In conditions of convergence those partners are likely to be harder to find and have different norms in terms of capabilities and culture (Dingler & Enkel 2016).

Developing innovation under conditions of convergence, with diverse technologies, requires the formation of alliances; defined here, as by Kale et al (2002, p.748) as '*any independently initiated inter-firm link that involves co-development, sharing or exchanges'*. The alliances provide the basis for resource heterogeneity (Penrose 1959; Wernerfelt 1984) with the unique combination creating the possibility to generate rents, by creating and capturing value. They could be considered as enabling an *extended enterprise* model (Gulati et al. 2012) where a focal firm (or group of firms) contracts with upstream, downstream, or horizontal partners that possess complementary assets to enhance their own technology, capabilities, or market reach. Specifically, Sebastio and Golicic (2008) argue the case that the successful emergence of a new market, based on a 'radical technological' intervention, depends largely on the parallel development of a new value network to support commercialisation activities. Adner (2012) extends these requirements beyond the value network itself to consider the wider 'adoption chain' necessary to commercialise the innovation and, hence, capture value. These activities can be considered as market creating, using a *constructionist* approach (Jaworski et al. 2000) as partners seek to complement knowledge and capabilities to create value (Lepak et al. 2007). It is not sufficient to just innovate a product or develop a value network, it is also necessary to construct markets and navigate institutions, which requires collective entrepreneurial action (Santos & Eisenhardt 2004; Santos & Eisenhardt 2009) and, a process of exploration to effect a transformation, or 'effectuation' (Sarasvathy & Dew 2005) amongst multiple alliances.

Alliance and Value Network development

Alliance formation and alliance management (Schreiner et al. 2009) under conditions of high uncertainty, would therefore appear to be a critical capability in the development of 'nascent value networks'. In organizational terms, this may be considered as the 'conception and development' stage (Kazanjian & Drazin 1990), either as a new venture (start-up) or as a new business unit within an incumbent firm. Harrington and Srai (2016) describe the stages of emergence of value networks and their characteristics, the network stages and transitions from 'embryonic' to 'fragmented' to 'formation' being the most relevant to the study of nascent value networks. A factor influencing the formation is the extent to which the networks or alliances are formed as a result of an emergent process or engineered, via a dominant player (Doz et al. 2000). According to Doz (2000, p.255) an "*Emergent Process may be more closely associated with alliances designed for exploitative purposes. Similarly, alliances designed to produce innovation, to explore new market opportunities, to enhance firm capabilities – so-called explorative alliances – may be more closely associated with Engineered Process*".

Kale and Singh (2007) identified that an alliance learning process involving articulation, codification, sharing, and internalization of alliance management know-how is positively related to a firm's overall alliance success, these alliance capabilities being described as 'higher-order dynamic capabilities'. This research however, focussed solely on large established companies in existing industries. In the context of the formation of value networks in nascent ecosystems, they can also be considered as the quadrant of 'pre-formation value creation' (Wang & Rajagopalan 2015) and that a competence based approach (considering information search, codified routines and partner evaluation) may be appropriate. Draulans et al. (2003) recognizing that the majority of alliances fail, looked at capabilities for alliance success in inexperienced and established firms, concluding that learning processes are important, but only up to a point, and that inexperienced companies can benefit from training or the use of alliance experts and that the type of alliances and their diversity can also influence outcomes. This would suggest that context, i.e. the nature of the ecosystem is an important consideration. However, as identified by Stuart and Sorenson (2007), extant research focuses disproportionately on the consequence of the network (or ecosystem), rather than its origins (i.e. how they built it).

The crucial role of relational capabilities in developing and managing alliances has been demonstrated in the literature (Ireland et al. 2002). For example, prior research suggests that a firms *negotiating* capability (Simonin 1997) and its *governance* capability (Aggarwal & Hsu 2009) are strong determinants of alliance success, which would point to the critical role of relationships. Taking a relational view, the role of relationship specific investments, knowledge-sharing, complementary capabilities and effective governance (Dyer & Singh 1998) are seen as determinants of inter-organizational competitive advantage in the context of an evolving network (or ecosystem). A relational view of governance is typically underpinned by social exchange theory (e.g. Blau 1964), highlighting the role of relational norms, trust and control in social exchange.

Knowing the key stakeholders within an emerging ecosystem, and conversely being known within it, is critical in order to foster effective cooperation across the entire value network (Harrington & Srai 2016). Classical stakeholder management (Freeman 1984) would stress identifying all the stakeholders as a first step and then addressing issues of power and influence. However stakeholder salience is highly dependent on the innovators position within the ecosystem (Frow & Payne 2011). In emergent ecosystems, key stakeholders may not be immediate (Maignan et al. 2005), and so identification needs to be a continual exploration, with iteration and refinement. Making connections and then making sense of these connections and their potential contribution (Sutcliffe et al. 2005; Weick et al. 2012) points to heuristics, with experimentation and learning (Bingham & Eisenhardt 2011).

A major issue, yet to be explored, is how firms can *build* these capabilities and ensure they are developed in a complex evolving environment (Dyer & Kale 2007; Donada et al. 2016). Recent research points to *relational capabilities* being more important than internally focussed capabilities (Brinckmann & Hoegl 2011) as these are key to enabling the innovator to access wider resources and capabilities. Furthermore, the capabilities required to co-create with multiple stakeholders, implicit in this type of innovation, have had limited study (Kazadi et al. 2016). In summary, what is not clear are the key relational capabilities and underpinning routines needed to successfully effect the development of the innovation, to form the required alliances (with multiple co-creators) and value network in a nascent ecosystem. A further compounding issue is that such capabilities may influenced by external and/or internal factors (Doz et al. 2000), which has not been addressed explicitly in empirical research (Eriksson 2014).

This research studies convergent innovation in healthcare, within nascent ecosystems specifically focussing on the formation of '*embryonic*' or '*fragmented*' stages of nascent value networks (Harrington & Srai 2016), where the expectation is a transition from chaotic to the early stages of some structure. We take a relational capability perspective to explore - *how organisations innovate in complex, highly dynamic convergent and nascent ecosystems*, and specifically aim to address the strategic capabilities needed to develop value networks in such diffuse environments with multiple actors.

Method

Given the nature of the enquiry and the evolving nature of the setting, a qualitative approach was adopted (Anteby et al. 2014). We base our research on empirical analysis in longitudinal case studies. The design consisted of two main phases (see Figure 1). As the context for each case study is an evolving ecosystem, a broader exploratory phase, to understand the dynamics of the ecosystem was undertaken as it was expected that this may impact capability building. This first exploratory phase involved 27 semi-structured interviews from a wide range of ecosystem stakeholders, to better understand the ecosystem itself. Using the approach of Gioia (2012), first order concepts and 2^{nd} order themes were developed into aggregate dimensions. Following a further literature review, an Exploratory Framework (Phillips 2015) was developed which identified key factors considered relevant to convergent innovation and this was then used as an investigational tool and interview guide for the second, case study phase.

Given the dynamic nature of innovation and organizations' managing them, a longitudinal case study (Yin 2014) provides an opportunity to identify patterns of managerial action and capability development. The second phase involved continuing ecosystem interviews (to provide contemporaneous context) and five longitudinal cases.

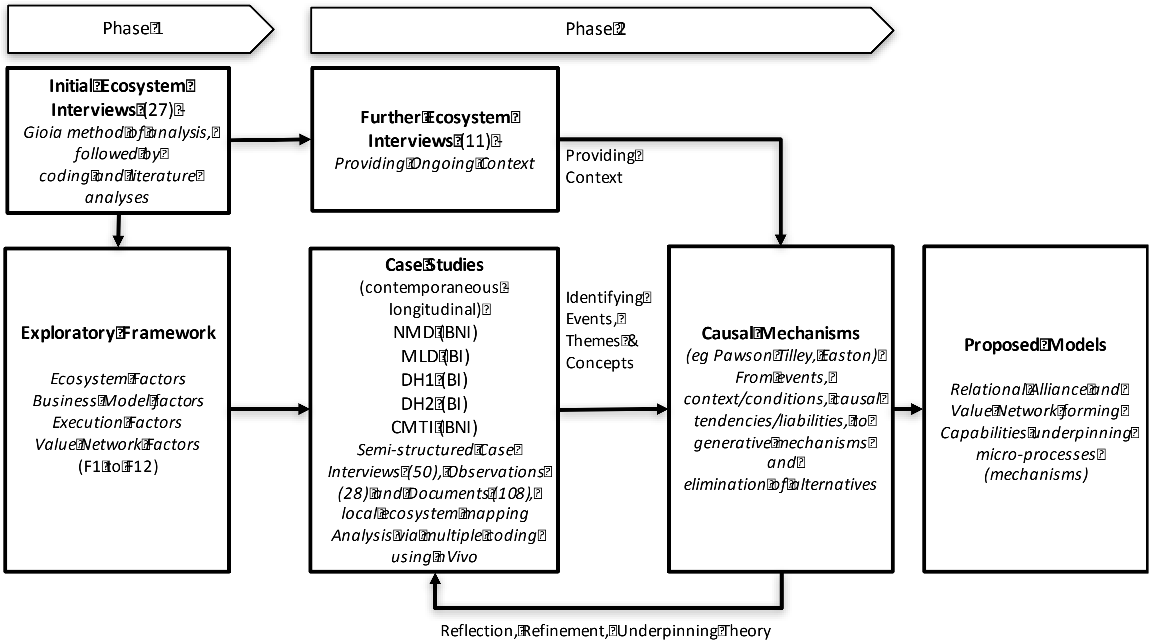

Figure 1 – Research Process

The five cases were selected from across three convergence domains (Shmulewitz et al. 2006), namely: biomedical sciences (B), novel and nanomaterial-based systems (N) and digital information systems (I)), with combinations of these domains enabling the development of ‘convergent medical technologies’, hereafter CMT. Each CMT case spanned a major phase or inflection point in the innovation timeline (to ensure that some significant or meaningful activity was incorporated). The cases included two large organizations, two start-ups and one incubator, where the focal firm could be considered as a ‘hub’ orchestrating activities (Dhanaraj & Parkhe 2006) in its network. For each case the exploratory framework was used as a guide for enquiry. In addition, the local ecosystem for each case was mapped (with input from the interviewees) at various time points during the case, in an attempt to capture its evolving nature.

The wider ecosystem continued to be studied with a further 10 interviews and attendance at 6 conferences and networking events (Table 1), the aim being to provide context to factors that may influence capability building. The five longitudinal case studies were conducted over a minimum 15-month period (late 2014 to mid 2016), employing a combination of and contemporaneous interviews with senior leaders, field observations (e.g. meetings and workshops), supported by current or recent primary documents (obtained under confidentiality), together with supplementary evidence from public documents. The 53 case study interviews, plus 29 observations and over 100 documents were collected (Table 2), coded and analysed.

Initial case coding, using qualitative data analysis software (nVivo^{TM}), was structural, derived from the exploratory framework using a mix of simultaneous holistic and sub-coding, and addressed internal and external activities. During the analysis, mechanisms were postulated from the observations and contexts (Pawson & Tilley 1997), which were subsequently coded and analysed using descriptive causation coding (Miles et al. 2014; Saldana 2013), alternative explanations were developed and eliminated based upon case evidence. As concepts and models were developed the data was re-queried. Later interviews were used to explore emergent themes and to understand the evolution of the capabilities and the innovators ecosystem, thereby giving some insight into the dynamics. Next, we performed cross-case comparison to identify patterns of similarities and differences across all analysed cases.

Table 1 – Summary of Ecosystem Interviews

Source	No.	Examples of interviewees / events
Initial Interviews ***(exploratory phase)***	27	CEO of Start-up, Investors, Venture Capitalist, Academic. MHRA, CTO Med Tech, VP Major pharma, CEO Biotech Incubator
Follow-up interviews (*conducted during Case Studies)*	10	Senior manager of OLS, SBRI, NIHR, InnovateUK. CEO of Biotechs. A serial entrepreneur.
Field Observations	6	Medical Technology conferences, digital health fora, workshops and meetings

Table 2 – Summary of Case Studies

Case	Organisation and Innovation Description	CMT Domains (BNI)	Interviews - interviewees and (n=) number	Number of Observations (Ob) and private/ public documents (D)	Summary of Key Case Activities and Status
NMD	New Innovation Unit in major pharma/med tech company developing an novel implantable medical device	BNI	R&D Head, Scientific Director, Head of Venture Fund, Business Development Director (n=13)	External workshops (Ob=1) Business Plan, Board papers, White paper (D=31)	Internal start-up. Major funding in place, with new governance board, alliance project underway and venture fund in place.
MLD	Start-up, developing AI/machine learning as a basis for screening, diagnosis and monitoring	BI	CEO, CTO, Medical Director, Investor, and Suppliers (n=14)	Board meetings, Technical meetings, Meetings with investors (Ob=15) Business Plan Development Plan Technical documents (D=23)	Start-up. In early development. Initial grants won. Pilot trial completed. Engaged in innovator funding competitions. Development trials underway. First major investor in place.
DH1	Innovation Unit in healthcare provider developing mobile and digital health applications for a range of medical conditions	BI	Managing Director, Project manager, Board members and senior managers of their Suppliers (n=15)	Team meetings Customer meetings Project kick-off and review meetings (Ob=8) Business plan Project review reports (D=24)	Internal start-up. Business plan for new company in place, run as wholly owned subsidiary for parent. First project delivered.
DH2	Start-up developing wearable and digital health solutions	BI	Chairman, CEO, CTO (n=5)	None (Ob=0) Business plan, investment options (D=9)	Start-up, attracted limited initial funding (grants). In process of identifying investors. *Terminated.*
CMTI	Incubator developing infrastructure and support for convergent medical technologies	BNI	CEO, Business Development, Board Members (n=6)	Company workshops Company conferences Internal review meetings (Ob=5) Board paper Internal review papers (D=11)	Have Board approval to develop full plans, ca 70% funding in place. Complementary investments in place. Range of ecosystem building activities underway.

Internal validity was addressed by conducting multiple iterations and follow-ups during the analysis. The use of detailed case study protocols increased reliability. External validity was addressed by using multiple cases and analyzing comparative findings (Eisenhardt & Graebner 2007; Yin 2014).

Ecosystem Findings

The exploratory research aimed to identify the ecosystem themes that may influence capability and value network building. The key 'aggregate dimensions', from Gioia's (2012) method above, are considered to represent the influencing factors from the wider ecosystem and are summarised as emerging themes in Table 3. The potential implications of these themes in terms of value network and capability building are also postulated.

Table 3 – Implications from Ecosystem Interviews

Emerging Theme	Implications for value network and capability building
The emerging ecosystem is not well understood, new agile entrants and new models are meeting risk averse and fragmented stakeholders	Significant knowledge management and learning are required upfront to build understanding
There is a lack of Customer Engagement and understanding of future Business Models	Given the lack of clarity in the business models, developing long term alliances with clear value capture mechanisms may be challenging
New assets carry higher risk and less understood decision criteria	Governance and decision criteria need to reflect the uncertainty and inferred risks
Public R&D Funding and VC Investment are not well developed for the ecosystem, and funders perceive new risks	The lack of public funding may result in gaps or 'holes' within the 'ecosystem' knowledge base
Knowledge and capabilities are diffuse (spread widely). Diverse approaches and duplication of effort are evident.	Search approaches may need to be different, and direct comparisons of capabilities may be difficult.
The Value Networks / Supply Chains will require new alliances and new models	Existing and established decision models and approaches may need to be modified.
The emerging ecosystem contains organizations with wide variations in Culture and Capabilities	As well as technological and capability differences, the value network partners are likely to have different cultural attitudes and norms
Regulation, Legal and IP issues are more ambiguous in the emerging ecosystem	Regulatory complexity adds different risks to the innovation and value network
The is a lack of Infrastructure and Support organizations	There is likely to be a lack of certain specific capabilities and capacities within the ecosystem

These implications can be considered as challenges or barriers that innovator firms and their collaborators need to overcome to successfully build the innovation and their value network. The case findings are discussed next, with reference to how the case firms addressed these challenges.

Case Findings

The case findings cover a range of activities from early searches (for knowledge and partners), sense-making, to selection, management of their alliances and activities to develop the wider ecosystem. The findings are discussed in terms of how these activities link to building relational capabilities for developing nascent value networks in the context of the evolving ecosystem.

Searching

In terms of developing value networks, understanding the context as well as the potential actors was evident in all cases – "*But we are not just trying to understand who, we are also trying to understand the barriers and challenges"* – CMTI. The evidence of search processes, critical in a nascent ecosystem, suggest it needs to be adaptive; all the ongoing cases reported using a combination of structured searches (initially), but then relying more on connections suggested by their own contacts or extended contacts, in effect 'snowballing' (Goodman 1961) to extend their search reach. *"So, ... it was structured to an extent. A bit like a structured fishing expedition. We tried many different ways"*- **NMD.** This capability is not vested in one or two individuals but the wider team - *"We are well connected locally and continue to spend a lot of time networking. We are always making new connections so that gives us an opportunity to influence at national level."*- **DH1**

The nature of connections made in all cases suggests the role of *tertius iungens* (Obstfeld 2005) in a few key ecosystem actors, and the behavioral propensity for those actors to facilitate new connections; which is seen as central to the combinative or constructive activity at the root of innovation. However, it is suggested by evidence from several cases that these connections do not arise out of benevolence or altruism, but are an outcome of a tangible demonstration of credibility and commitment by the innovator (see later section on *selection*). Other networking approaches failed to result in any meaningful engagement, seen by the innovators as a consequence of lack of current interest (or priority) or that the other actors see nothing it in for them: *" We are continually exploring new possibilities, in terms of partners, investors and people we could work with for trials etc. I think one of the challenges here is unless you have the finance in place and can buy services, you need to have several options in play, because one might not come off, and you don't have any leverage. So they can just walk away. So building the network is critical "* .- **MLD**

Sense-making (and sense-giving)

As well as developing their own learning, the need for broader learning within the ecosystem was recognised in order to address the environmental implications of the nascent field. "*One interesting things was that in UK, there was no one, in academia, that saw themselves with a bioelectronics' (BE) label, but when you got underneath and found out what they were doing, they were doing BE related work. So the labelling and branding are important, and affect communication and understanding"* **CMTI.**

Case firms invested in activities to help build knowledge and enable sense-making via a range of relational activities. **"***To develop our thoughts, we have been bringing, as you know, experts, panels together, and running workshops"* **NMD.**

But these activities often extend beyond sense-making itself, the activities encompassed sense-making and sense-giving, in helping others to understand - "*I think that as we have evolved somethings have changed. But some things are core. Our approach is what you might call a 'spirit of inquiry' we want to foster 'learning together'. That's a very different approach to a Tech company coming along or even a HCP coming along with a 'solution'. Our approach is about creating buy-in from all users. To do that you need to be prepared to 'learn in public'. That means continually connecting via debates, workshops, meetings, 'show and tell'* **DH1**

Selection

The collaborator selection approaches varied markedly across the case studies. More often than not, broad criteria were used and formal contracts were initially short, usually focussed on a specific outcome, that created a new capability, reduced risk or progressed the innovation. No long term or strategic partnerships were formed in any of the cases at the start of the nascent stage. These tended to be put in place later on, once relationships had been built.

In all cases the later collaborators were often not those actors initially identified and engaged. During the nascent stage of the value network, alliances may be short term and more about addressing specific needs (i.e. being effective), rather than long term and about efficiency.

The data suggests that innovators need to build credibility (via existing assets and capabilities), in order to open up conduits for connection (e.g. conferences and meetings). "*Above all its important to be seen to be 'credible'. We need that to create legitimacy with patients and HCPs. So, as well as ideas, we have to bring 'assets' - examples of things we have made happen, and delivered. That lets people really understand what you are doing"*- **DH1.**

Furthermore, as well as credibility, there is evidence of a need to identify and build complementary 'assets' and visibly demonstrate commitment, in order to collaborate. *"We started with a systematic search, .., we aspired to it, but that's not how it worked out over time. That initial search led to us accessing three key individuals who we collaborated with .... That provided a key to access more people. It was not so much that they opened up their Rolodex, as by working with them we had more credibility from those interactions ... so we were perceived as serious and credible. That was key. As I mentioned the open OI calls did not deliver many collaborators, but maybe provided another signal of our intent*." - **NMD**

A further factor is timing, even if there is a technological opportunity to engage, other factors may influence an actor's decision to collaborate, which may simply be timing: *"To be honest, it's a bit like Brownian motion. You are forever moving around, bumping into different people. And you cannot predict beforehand whether they will add value or not, or even immediately after. Also its something about when you do business and have the meeting. So it's not pre-determined, it seems completely random. You might expect them to be interested based on your prior knowledge, but it's not always like that, and it might just be timing or it doesn't fit their exact interest".* **MLD**

Finally, common interests and timing (congruence) appear important. *"I'd describe the common interest as something more, there needs to be 'congruence' a real alignment, not just in terms of the outcome, but also cultural and how you are going to do it. Connections do not just happen. You need to 'cultivate' to create the right opportunities. That is where I see this spirit of generosity and being open, learning together as being important"* – **DH1**

Much of the work in the nascent phase appears to be about identifying and addressing near term needs to build evidence and address risks. Often, collaborators are identified via the innovators network, or network of their network, rather than structured searches. A summary of case evidence and insights in terms of searching, sense-making and selection are provided in Table 3.

Table 3 – Summary of searching, sense-making and selection evidence and insights

Example Case Evidence and source	Insights from Cases
Searching:	
"It's fairly structured. We started with people we know. But are now expanding the interviews, talking to their suggested contacts. We want to extend our search beyond the usual suspects". **CMTI**	Searches via a combination of structured searching (of known domains) and snowballing, using the wider network to expand the search areas, but in a structured way to help address '*distant*' knowledge.
Sense-making/Sense-giving:	
"So it's like a bit like a deep dive in…and reflecting and then looking in another area…an iterative process…and trying to make sense of it, so do I have enough information, is it meaningful? Can I identify a hypothesis?" **NMD** *".. Conferences rarely engage patients. We are therefore going to run a one day (un)conference – that helps positioning – on 'people driven' health and well-being, ... So the input is all from personal experience, and participant led".* **DH1**	Sense-making through developing 'propositions', going beyond immediate contacts and network to 'test' the idea with stakeholders who responses may conflict, helps improve the sense-making/giving process and increase objectivity. The ability to connect and make-sense depends not just on content, but on timing and mutual interest (and the stakeholders' current priority).
Selecting (Collaborators):	
"We partner with experts wherever they are and drive much of our research through partnerships" **NMD** *'The experimental work to date has by and large not been conducted at [NMD], but instead by ~100 researchers in the ~50 collaborations the team has led and integrated".* **NMD** *"We are doing most of our current work through alliances or partners now. …. Nearly all of these have been found via our network (connections to connections). That's how we found the VR firm, if we'd done a traditional search I don't think we would have found them or even considered them.* **MLD** *"We tend to go back to the same ones. Sometimes we use a competition, sometimes we use Single Tender Waiver – where we know there is only one who can provide what we need. We are not just looking at price. We are looking at the relationship too. Back to what I said earlier, it's about alignment."* **DH1**	Extensive use is made of collaborators, but few turn into long term alliances. Collaborators are often not those initially identified or engaged, but they may provide conduits to other collaborators. Therefore physical engagement – at meetings, conferences – is a key step. Selection often involves broad strategic aims or interpretation, rather than precise criteria, balancing making near-term progress against longer aims. Where collaborators are re-engaged its often driven by alignment.

Having selected early partners there is then a focus on providing governance (some degree of control) and developing the innovation and required support network.

Governance

The cases demonstrated a range of approaches to governance of the innovation and supporting value network. Unexpectedly in all the cases there was a need for agility. Established firms put in place mechanisms to provide an overall approval of strategy, but then invariably used empowered teams to execute: "*Once it's all approved we will have a highly empowered autonomous team to give us the agility we need*." **NMD**

Where more senior approval was required, the mechanisms are kept simple: "*So, we were agile where we just needed [···] sign off on individual projects (after overall CET endorsement) using one pagers and probably got 90% approved"* **NMD**

Smaller organisations used a range of approaches to provide effective governance, but key is the maintenance of regular contact: *"But we are still managing most of our work through informal meetings, emails, Skype calls etc. We keep our formal meetings to a minimum. It seems to work, our partners seem happy with the approach and we continue to make progress."* **MLD**

When questioned about ability to use existing governance structures (in larger firms) they responded, that they were generally inappropriate: *"it's not in their remit. And they don't have the right members. So we are bringing in external ones, from medical devices, tech company backgrounds. It may be three internals, three externals or four internals and four externals. But not bigger than that."* **NMD.** The key issue being suggested was that existing structures did not have the required knowledge and capabilities to make the necessary judgments. Interestingly large organizations were prepared to engage the ecosystem and collaborators to ensure the decision criteria made sense: *"The team has worked together with a group of subject matter experts to define the following detailed success criteria, building on high-level specifications for the device and its functionality."* **NMD**

This evidence points to the need for agile governance, with directional, rather than defined decision criteria. Given the inherent risks at this, making use of the wider network is valuable in helping to validate investment decisions or reduce risks.

Investing in the value network

Beyond direct investment in their own innovation and capabilities, there is evidence from both large company cases for the organizations investing in broader 'ecosystem' building activities. As an example one firm ran and funded an open innovation competition and then ensured that the resulting platform solution was available to the wider ecosystem: "*Acceptance of the prize will require, .. that the .. winner (or the entity that owns or controls the relevant IP) release all relevant research data and information into the public domain, but only after such parties have been given the opportunity to protect rights for future commercial application. This public release of data and design will allow other investigators, including those at [NMD], the right to utilise the work for future research purposes while permitting the … winner (or the entity that owns or controls the relevant IP) to retain commercial rights."* – **NMD.**

Similarly, in another case the innovator firm helped fund a support organization (a contract clinical research organization) to provide support services to alliance partners to complement their capabilities and resources. By providing these services, risks from capability gaps elsewhere in the network are reduced.

These acts are considered to be more than altruistic, they build the capabilities of the wider network, and also cement the position of the integrator firm, helping to build credibility and ultimately legitimacy, seen as important to develop longer term relationships.

Developing a capabilities framework

Harrington and Srai (2016), identify three perspectives on capabilities for developing a 'resource portfolio': defining network roles and responsibilities, re-grouping resources to build capabilities and leveraging existing capabilities. The resulting networks and capabilities are defined in the context of six '*configuration elements*' that need to be addressed as value networks are developed. Taking these six elements as a framework, but reordered, the case evidence has been framed as example capabilities for each element, and summarised in Table 4.

Table 4 - Network Creation Capabilities (adapted from Harrington and Srai 2016)

Configuration Elements	**Example capability considerations**
Relationships	Search for partners and process selection, developing relationships
Structure	Leveraging existing, initial partnering and emerging clusters
Network Dynamics	Demonstrating 'credibility' and 'value' to their network
Governance and coordination	Balancing control and agility in decision making
Support infrastructure	Providing resources to support development
'Product'	Shaping the value proposition, developing a 'product' focus

Bringing together these insights, a suggested suite of activities and potential capabilities emerges. We have tentatively clustered these into phases of navigating, negotiating and nurturing to develop the alliances and nascent value network, as depicted in Figure 3.

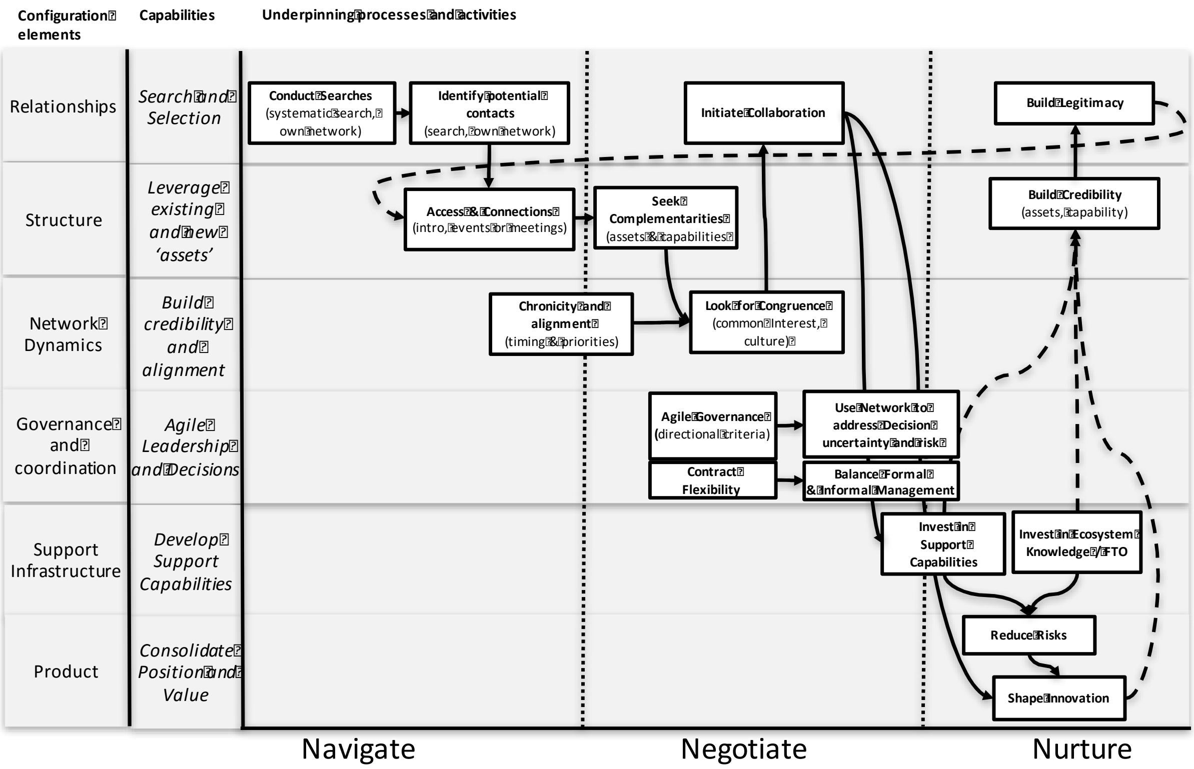

Figure 3 –Summary of Case Formation Processes for Nascent/Emergent Value Networks

Of the five cases studied, four were still successfully operating at the end of the research period, but one innovator, case DH2, had failed, after about 9 months. A follow up review with the management of that case identified two key contributors to that failure – one, failing to identify critical competitive activity (for example by not conducting their search and sense-making activities with enough rigour) and secondly a failure to attract investors from their existing network (pointing to the need to search beyond their existing network).

Discussion

Early alliance formation requires a balancing of tendencies for both exploration and exploitation (Lavie & Rosenkopf 2006), here we suggest that the domain dictates that

explorative action is required first in order to conduct *creative search* (Pandza & Thorpe 2009; Garud & Gehman 2012). Then, that *sense-making* (Weick 1995; Thomas et al. 1993) via inter-subjectivity, and absorptive capacity (Cohen & Levinthal 1990; Enkel & Heil 2014) are employed to recognize, assimilate and act upon new 'exploratory' knowledge (Kim & Atuahene-Gima 2010) in a domain of high equivocality and high uncertainty (Daft & Weick 1984). The search for insightful stakeholders and then sense-making is critical, but challenging, as different stakeholders have different (and sometimes conflicting) perspectives about value (Garriga 2014), particularly in a healthcare setting. Diversity in innovation alliances is recognised as important (for example Nieto & Santamaria 2007), in many of the cases the innovators found that later collaborators were often not those they had engaged early on and so building flexibility into the search and collaboration practices, and undertaking activities to demonstrate 'credibility' are potentially important precursors to accessing *tertius iungens* actors (Obstfeld 2005); those actors who enable and potentially catalyse further interactions and network building. In the cases, those interactions were invariably face to face, reinforcing the importance of direct engagement (Nonaka & Konno 1998) and the socialization aspects (Dingler & Enkel 2016).
Tsanos et al. (2014) identify that these antecedents are important in building supply chain collaborations. Such actions also build both trust (Todeva & Knoke 2005; Larson 1992), however this trust appears to be needed beyond simple dyadic relationships, instead requiring that trust to be built within the context of the emerging network or wider ecosystem, through both action and visibility (), The process, are thus more complex and nuanced than implied in extent alliance forming literature. The case evidence would point to both 'emergent' and 'engineered' processes (Doz et al. 2000) being adopted. Making reference to Doz et al. (2000, p.254), whilst considerable evidence for an 'engineered process' exists, via options exploration, aligning domain interests and filling structural holes. There is also evidence of 'emergent processes' with a need for similar interests, defining boundaries, and evidence of learning.

These approaches would support that moving into 'uncharted territory' where '*potential partners are neither actors you can easily identify nor are they (once you find them) likely to be keen to engage with you'* (Birkinshaw et al. 2007), requires different network building approaches. However this research would suggest that alternative paths to those identified by Birkinshaw et al. (2007, p.81) are available to innovators. None of the five cases attempted to use 'independent network-builders' but instead invested themselves, it is suggested that in such networking activities as the act of direct engagement was a seen as precursor to building credibility and trust and importantly by directly engaging the innovator is able to build meaningful domain knowledge and understanding to absorb insights from these partners.

The uncertain nature of the environment also makes decision processes challenging, organizations appear more likely to rely on interpretation and broad criteria (Dean Jr & Sharfman 1996; Daft & Weick 1984), as part of their 'exploitative' learning process (Kim & Atuahene-Gima 2010). There evidence that innovators engaged their ecosystem to help in investment decisions that had implications beyond the firm has the internal effect of reducing risk and the external effect of being seen to value the other ecosystem or network actors; this reciprocity being important in building wider trust.

With the larger organization cases, investments were made to actively support or nurture the alliances and ecosystem, by providing resources, or supporting open innovation programmes or direct investment. Smaller firms tended to nurture their alliances more by actively engaging and maintaining relationships, than by direct investment in others' capabilities. These steps appear to be more than just reactionary; they are creative and anticipatory processes (Rosen 1985) suggesting a combination of both path creation and path dependency (Garud et al. 2010; Sydow et al. 2012) or of causation and effectuation (Sarasvathy & Dew 2005; Chandler et al. 2011), or both (Sitoh et al. 2014), as innovators engage the network to *shape* their offerings and the required capabilities. In convergent innovation there is increased risk complexity and interconnectedness (Hellström 2003) with potential risks in the technology, its integration (Smith et al. 2013) and in the commercial model, and also with different stakeholders having different perceptions of risk (Hall et al. 2014). So, focussing on value creation alone is insufficient, there is also a need to invest in the value network and the ecosystem itself (Smith et al. 2013), thus these *relationship specific investment*s help to *sustain* the innovation, and ecosystem, by making and encouraging network connections (Garriga 2014).

Conclusion

The objective of this research was to address the challenges of innovation in convergent and nascent ecosystems and specifically to understand how nascent value networks are formed.

By addressing each case, its local ecosystem and wider ecosystem our approach takes a step in addressing the challenge of identifying both internal and external enablers (Eriksson 2014). Although limited to a few cases in a nascent ecosystem, by taking a contemporaneous and longitudinal case approach, we address an identified gap in the literature on '*how*' organizations develop value networks in this context, making a contribution to the value network and associated relational capability literature.

Our research further contributes to the empirical study of convergent innovation, notably in a healthcare technology setting. As previously noted, this is an important area in practice, yet has been subject to very few empirical studies.

Further longitudinal case studies, including those in different convergence domains with nascent ecosystem and value networks, would be a useful extension to build a more comprehensive model of an increasingly important area of innovation.

For the practitioner, or innovator, an approach to building nascent value networks is suggested that requires multiple engagements with diverse stakeholders, as part of a search, sense-making and selection process, but importantly also helps to create credibility and visibility, necessary to form alliances. Innovators have an opportunity to shape outcomes and their value network, but the importance of supporting and sustaining the nascent or emergent ecosystem is also identified as a key activity. The insights provide potentially important areas for innovators to focus particularly in terms of approaches to identify and engaging with collaborators by creating credibility and looking for congruence beyond just technical capabilities, in order to build alliances and the value network.

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Developing a model to conceptualise a more digitally connected pharma/healthcare value network

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Abstract

This study focuses on the impact emerging digital technologies may have on the pharma/healthcare ecosystem. It seeks to build on the relatively new field of digital/IoT-based business models, where only minimal, generic frameworks are discussed in literature. It is argued that healthcare and pharma value chains have been operating as independent entities and limited research has explored the potential for Product-Service Systems to span both industries. A distinct disconnect was also identified between pharma and patients, resulting in virtually no interaction or feedback between the two.

A comprehensive model for a more 'digitally' connected value network is proposed. The model strives to simplify the complexities of the conceptual ecosystem and could enable companies to better understand potential relationships, serviceable aspects, data flows and revenue streams, previously unconsidered in literature.

Keywords: Healthcare, Pharma, Value Network, Digitalisation, Servitization

1. Introduction

As global life expectancy continues to rise, and the spread of chronic illness intensifies exponentially, the current nature of care is rapidly becoming unsustainable. Consequentially, there is mounting pressure on healthcare and pharma sectors to adopt new models of care and medication to meet the individual needs of a growing population more efficiently and effectively (Brach, et al., 2005).

The world is also becoming ever more digital. In the last decade the emergence of disruptive, digital technologies, such as big data analytics and the IoT, has impacted customer expectations and human factors in ways never seen before: patient demand is not just increasing, but its fundamental nature is changing (Jimenez, 2015). E-technologies are transforming the rules of the global healthcare landscape (Champagne, et al., 2015), making the concepts of personalised medicines, treatments and remote healthcare services a distinct reality. However, radical transformation (with respect to healthcare and pharma's structures, processes and technologies) is still required to embrace a more digital era and address the modern issues of growing life expectancy and chronic illness (Taylor, 2015).

Michael Porter defined the term 'value chain' as *"the entire production chain from the input of raw materials to the out-put of final product consumed by the end user"* (Porter, 1980). In this study, it is argued that pharma and healthcare value chains have been operating as independent entities. The research seeks to challenge the status quo by exploring the impact disruptive, digital technologies and advancements in re-distributed, continuous manufacturing processes could have on the ecosystem. This may enable a novel approach to assess the feasibility and advantages of a more 'digitally' connected value network.

The study is set in the boundaries of chronic disease treatment within the UK healthcare/pharma industries. The sector is a challenging environment, regarded by many academics as one of the most complex and interesting ecosystems to study (Campbell, et al., 2000). It is characterised by numerous stakeholders and regulations, with an overarching focus on patient safety and wellbeing. Human factors is a distinctive challenge in the state funded system as patients believe they have the right to the best possible care, provided free at the point of access.

2. Literature Review

Advancements in digital technologies are becoming increasingly more disruptive and are facilitating a new age of healthcare based on remote data collection and analytics. This is supported by a report by Manyika, et al. (2013) which states the top four technologies likely to have significant economic impact by 2025 to be the mobile internet, automation of knowledge work, the IoT and cloud computing. This review discusses the literature concerned with relevant digital technologies and business models.

2.1. Wearable/Monitoring Devices

The literature surrounding digital, wearable technologies is growing increasingly broader in context. Numerous literature reviews were sourced on technological advancements, including (Rodgers, et al., 2015); (Taylor, 2014); (Wang, et al., 2014) and (Chan, et al., 2012). There are also multiple applications for digital wearable-devices discussed in the literature, focusing on areas such as monitoring cardiovascular, diabetes and respiratory diseases (Rodgers, et al., 2015); (Wang, et al., 2014). The specific parameters now possible to monitor are also well documented (Chan, et al., 2012).

Using diabetes by way of an example, the rapid rate of innovation in wearable monitoring devices, found within literature, has been illustrated on a timeline (Figure 2-1). This displays the key stages in the evolution from a simple glucometer, invented in 1970, through to the modern day where entrepreneurs and academics are utilising advanced technologies, such as micro-electronics, to develop cutting-edge non-invasive solutions.

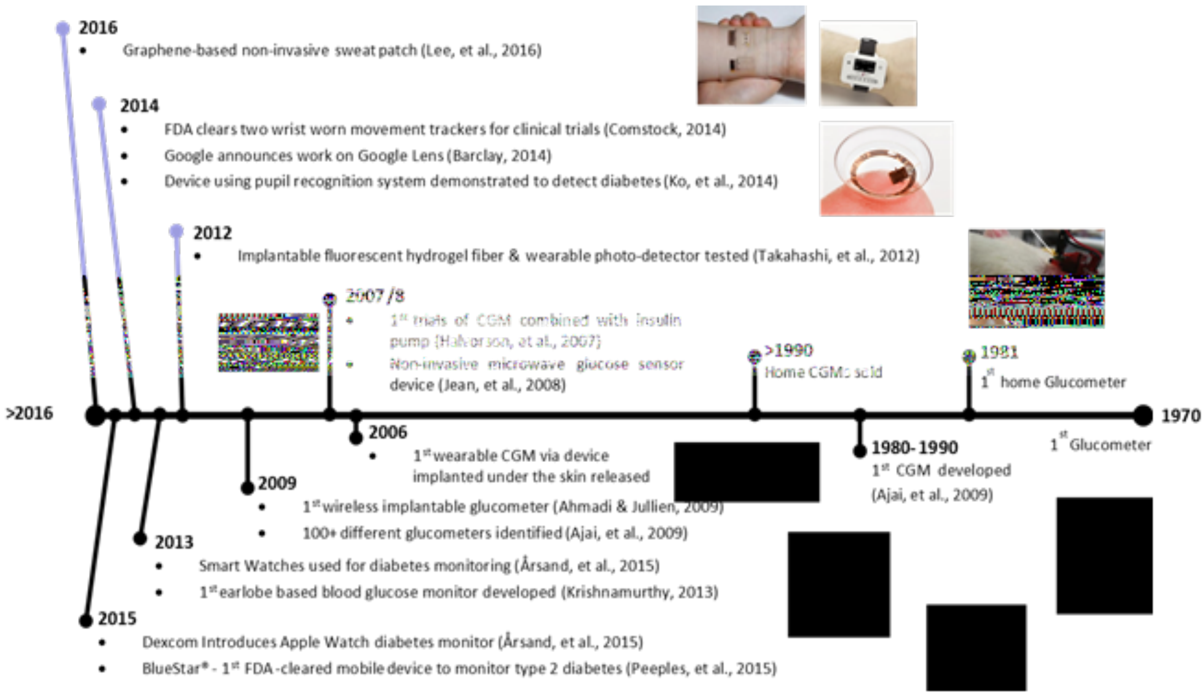


Figure 2-1: Innovation in wearable technologies

A key advancement found in the literature was completed by the 'Centre for Nanoparticle Research', Korea. Researchers have developed a wearable patch, worn on the skin, which measures blood glucose levels through sweat, using micro-electronics. The data is continuously transmitted automatically to a receiver from the device. The minimally-invasive patch can also administer small amounts of Metformin through micro-needles on its surface (Lee, et al., 2016).

Major technology firms, such as Google and Apple, are now venturing into the chronic disease monitoring market. Google has partnered with leading pharma company Novartis to develop a device called the 'Google Lens', capable of monitoring blood glucose levels in tears (Barclay, 2014). Apple has partnered with Dexcom and released an App to work with Dexcom's 'Share2 GCM device'. The sensor (implanted under the skin) transmits data via a smartphone, to healthcare professionals. It can also be sent to the watch, allowing users to easily monitor their condition through real-time graphs and alerts (Neithercott, 2015).

In addition to several successful proof of principle concepts, there have been failures. The 'GlucoWatch® biographer' was developed over 15 years ago to be the first minimally-invasive glucose monitoring watch (Tierney, et al., 2001). The device extracted glucose through skin by 'reverse iontophoresis', which was subsequently detected by an amperometric biosensor. However, due to complaints that the device provoked skin allergies, the FDA later banned the product (Chan, et al., 2012). Nonetheless, more recently, the FDA have cleared two wearable-devices for use in clinical trials. The devices designed by Camntech include the 'MotionWatch 8' and the 'PRO-Diary'. These are intended for the acquisition and analysis of movement data and can be pre-loaded with survey questions, enabling users to provide feedback throughout the trial (Comstock, 2014). There are no approved wearable-devices for use in drugs trials at present, yet findings indicate this may be a future possibility.

2.2. The IoT and E-Healthcare

The literature surrounding the IoT and e-healthcare consists of three architectural layers, namely the wireless sensor network (WSN), e-Health gateway and the application/back-end system (Rahmani, et al., 2015); (Sun, et al., 2012). The first layer (WSN) integrates various autonomous sensors, usually incorporated into wearable technologies, into a network of health data collection. The second (e-Health gateway) is concerned with how said data is transmitted to an external body (such as physicians). The third layer (back-end analysis) is defined as where physicians may access and analyse the collected data to enable the provision of remote advice.

The literature details various examples of complete e-healthcare solutions (Rahmani, et al., 2015); (Yang, et al., 2014); (Doukas & Maglogiannis, 2012) and (Dohr, et al., 2010). The later proposes an e-healthcare system for ambient assisted living. It consists of wearable blood pressure sensors which forward the health data of chronically ill/elderly people, through a smartphone, to physicians. Using the sensors equipped in a smartphone, additional data such as activity is transmitted simultaneously. The physician can utilise the amalgamated data to monitor their health status and adherence, offer advice and optimise treatment remotely. This creates a more effective relationship between the patient and the physician, and enables relatives to remotely care for patients (Figure 2-2).

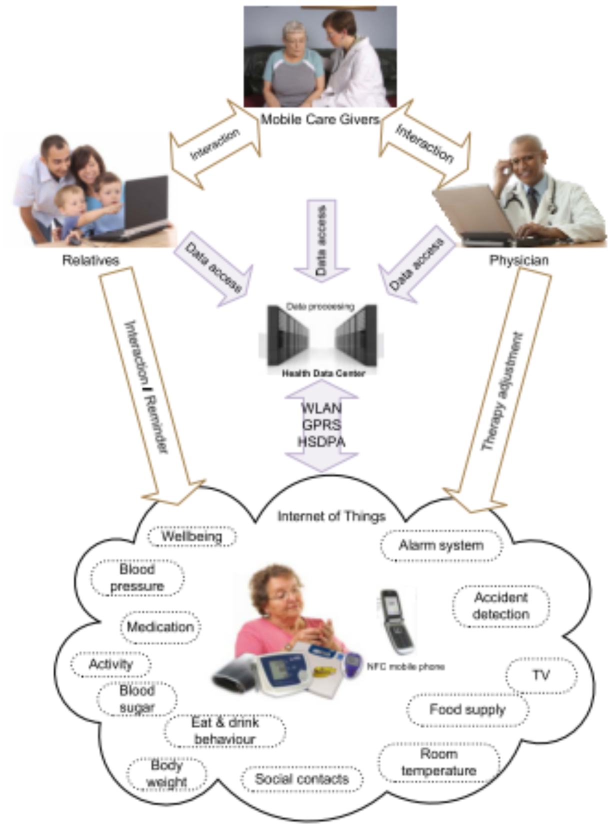


Figure 2-2: Example of e-healthcare system (Dohr, et al., 2010)

2.3. Product-Service Systems

Taylor (2014) states that pharma has long been considering a transition from product-oriented business models to alternatives more closely focused on serving the needs of patients – potentially through services and the use of wearable-devices. An example of this is that of 'Equally Zeneca' (now 'AstraZeneca') who acquired 'Salick Health Care' in 1997. They operate a fully integrated cancer and chronic care service in the US, which facilitates performance monitoring of their own and competitors' drugs (Howells, 2000). An example of a Product-Service System (PSS) in the healthcare industry is 'G.E.' who have a maintenance based PSS for their CAT and MRI imaging products (More, 2001).

Despite the fact that the concept holds great potential to address major challenges within the healthcare sector, PSSs are relatively unexplored in the related literature (Mittermeyer, et al., 2011). The few identified include (Yip, et al., 2015); (Ryan, et al., 2014); (Velikanov, et al., 2013); (Mittermeyer, et al., 2011); (Köbler, et al., 2009) and (Ajai, et al., 2009). The latter is deemed to be the most important, in the context of this study. It details the design of a results-orientated PSS for point-of-care devices. The paper presents a case study of glucometers used to collect diabetics' health data and transmit it back to healthcare professionals, enabling the provision of remote services (Figure 2-3). In the paper, blood test reminders and external analysis of results are provided as examples for serviceable aspects made possible through more of a 'closed system'.

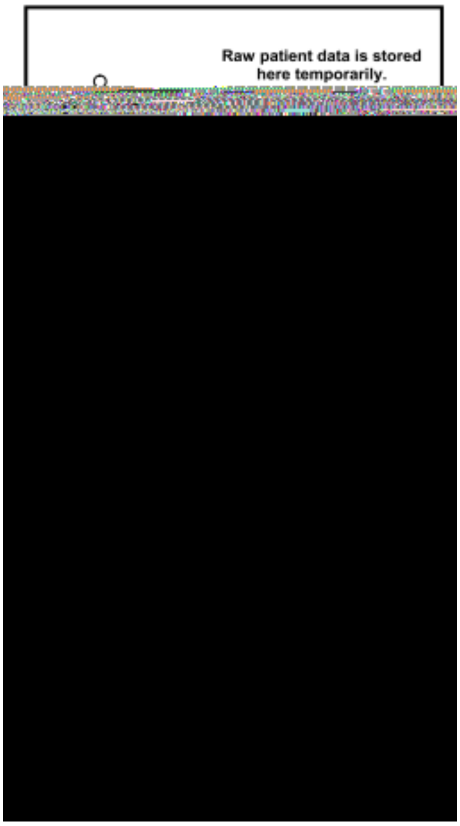


Figure 2-3: Schematic of PSS for point-of -care devices (Ajai, et al., 2009)

Limited literature discusses the potential for a PSS model spanning both healthcare and pharmaceutical industries. The paper by Mittermeyer, et al. (2011) comprises of a comprehensive case study, detailing B2C and B2B relationships and product/service components of a drug/device combination, used for the treatment of cancer in hospitals. The paper, however, does not contain any reference to wearable-devices, the IoT or base any serviceable aspects on digitisation.

2.4. Future/Digital Business Models

As the world becomes more digital there is an increasing need for pharma and healthcare to adopt patient-centric (digital) business models and supply chains (Srai, 2014). Digital/IoT based business models was identified as a relatively new field with limited frameworks sourced from the academic literature (summarised in Table 2-1).

Table 2-1: Summary of contributing literature on IoT business models

Authors/Date	Paper Summary & Framework Description
(Chan, 2015)	• Literature review of IoT business models published to date • Development of a generic model, tested through six company case studies
(Dijkman, et al., 2015)	• Comprehensive literature review of IoT business models published to date • Development of a generic model based on the business model canvas (Osterwalder & Pigneur, 2010)
(Sun, et al., 2012)	• Proposes a 'DNA' – Design, Needs & Aspirations framework • Application case study of framework in smart-logistics industry
(Fan & Zhou, 2011)	• Framework developed specifically for the postal logistics industry
(Liu & Jia, 2010)	• Detailed overview of where IoT could be applied in drug supply chain • Two business model framework variations proposed

These limited models were found to be mostly generic with only Liu & Jia (2010) concentrating on the healthcare/pharma industries. The authors highlight the key actors involved in the drug supply chain and their value interfaces (flow of goods, services and finance). Figure 2-4 shows one of the two model variations proposed, focused on the 'terminal equipment provider'.

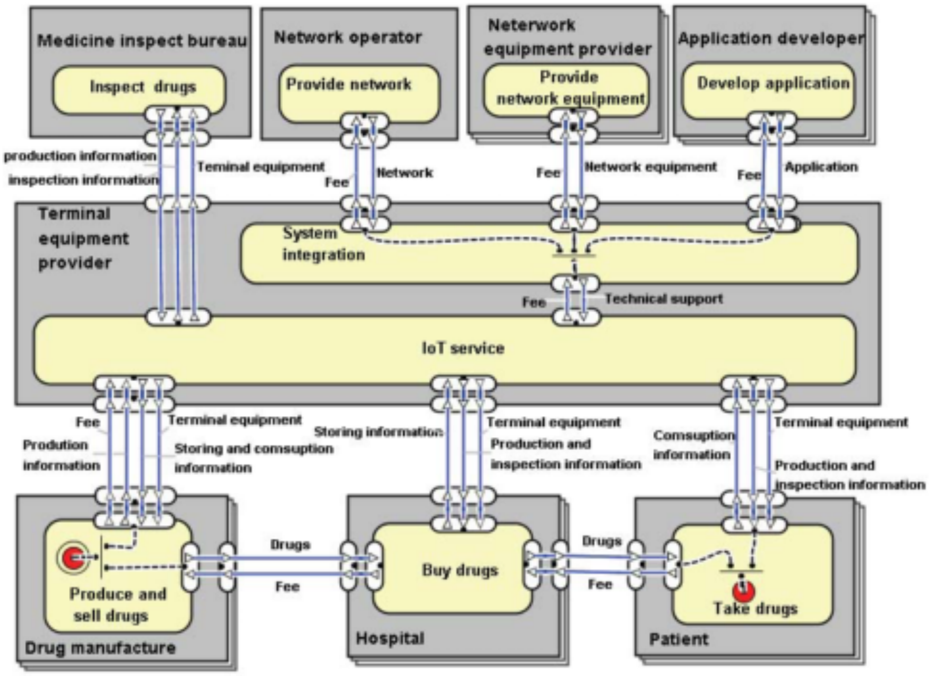


Figure 2-4: Drug supply chain IoT business model (Liu & Jia, 2010)

Both models proposed by Liu & Jia (2010) demonstrate a distinct disconnect between the drug manufacturer (pharma) and the patient, with little to no interaction or feedback detailed between the two. This was a recurring theme found across the review: echoed in the supply chain literature (Pedroso & Nakano, 2009). The models primarily concentrate on how the IoT could help drug manufacturers optimise inventory and supply processes, whilst assisting hospitals improve the traceability of drugs. The paper, as well as literature in general, does not detail how both pharma and healthcare collecting and sharing data through the IoT could enable services (such as personalised medication and/or remote treatment), nor does it detail how said data could be collected/transmitted. Moreover, the paper details only a simple product-fee relationship between the two industries, without considering the value potential of a more digitally connected partnership.

2.5. Pharma and Healthcare Value Chains/Networks

Literature was reviewed and compared on how the pharma and healthcare value chains are depicted in academia, culminating in the creation of the two simplified, generic versions, shown in Figure 2-5&6 respectfully.

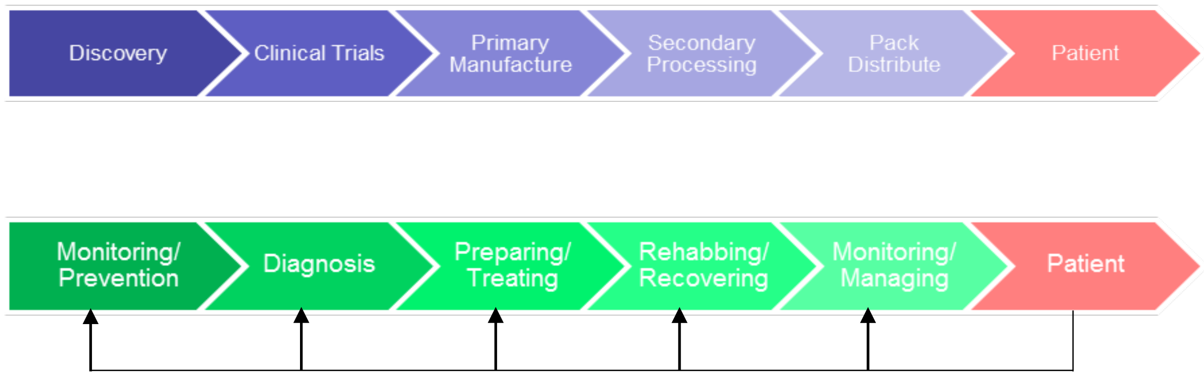


Figure 2-6: Healthcare value chain (Porter, 2005); (Burns, 2002)

The main similarity between the two chains can be seen as their focus on the patient. However, the key difference identified is there are no distinct linkages or feedback between 'stages' within the pharma chain. Moreover, there was no evidence found to suggest the two are currently directly connected, how best they could be, or what opportunities this may present.

Although no literature was found to consider both pharma and healthcare, a basic conceptual value network for the adoption of e-commerce in pharma is documented by Allee (2000). Figure 3-1 shows the framework proposed for mapping value networks, clearly articulating the flow of goods, services, revenue and knowledge between actors.

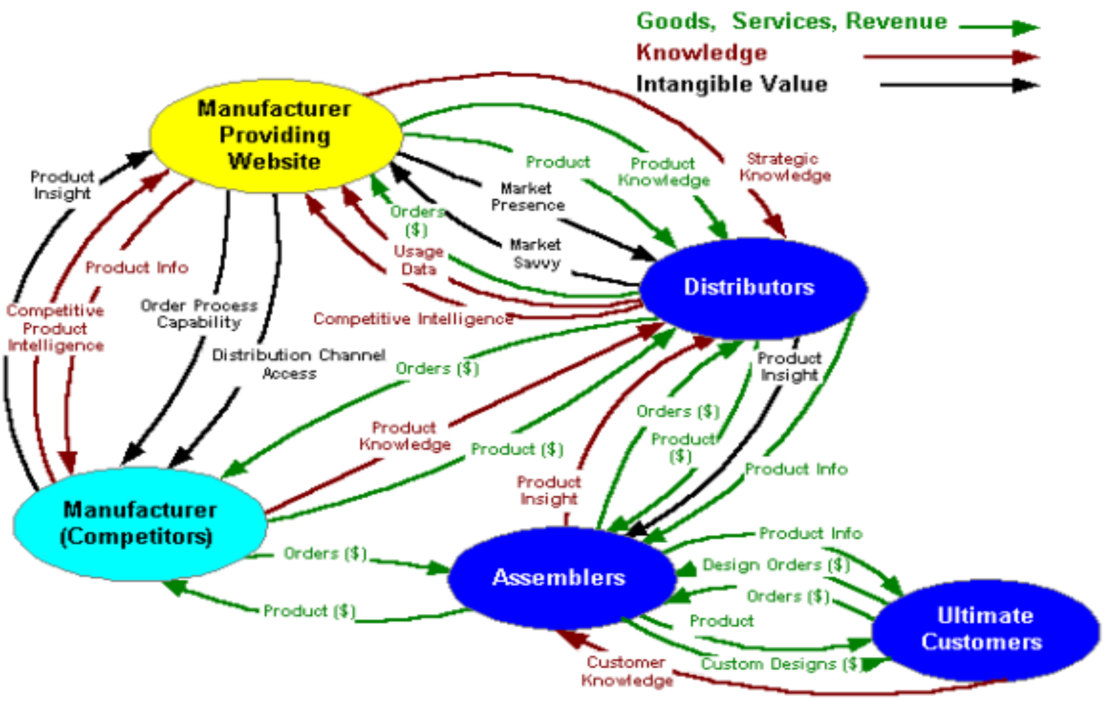


Figure 2-7: Conceptual pharma e-commerce value network (Allee, 2000)

2.6. Continuous Manufacture, RDM & Personalised Medication

Conventionally, drugs have been manufactured in batch production methods. However, due to supply chain pressures and advances in production technologies, a considerable volume of literature is now focusing on transitioning to continuous manufacture (CM) and re-distributed manufacturing (RDM).

CM is where materials and product continuously enter and exit the production system, respectively, throughout the entire duration (Lee, et al., 2015). RDM is a shift towards smaller-scale, local manufacture, characterised by the potential for greater product personalisation (EPSRC, 2013). These innovations are being enabled by various emerging, disruptive technologies, manufacturing processes and are forecasted to radically transform the dynamics of supply chains, business models and industrial ecosystems. CM and RDM together will offer the advantages of meeting unmet needs and cheaper production/supply costs, as well as greater product/volume flexibility, inventory reduction, faster supply and improved quality (Harrington, et al., 2016); (Srai, et al., 2014); (EPSRC, 2013).

A particularly interesting example of CM/RDM technology is 3D printing and/or Inkjet printing. These machines could be used to continuously print pharmaceuticals and personalise medication. In papers by Srai, et al. (2014) and Daly, et al. (2015) the concept of a machine capable of printing personalised pills, programmed with patients' prescriptions, is conceptualised. The printer could theoretically combine multiple ingredients together to create a singular pill to treat ailments, and be fabricated in localised manufacturing units.

2.7. Digitalisation of Pharma/Healthcare Supply Chains

As the nature of the pharmaceutical industry changes with fewer 'blockbuster drugs' and R&D productivity declining, gaining operational efficiencies is growing more critical (Harrington, et al., 2016). The focus on niche (personalised) products to serve new and multi-faceted markets, will require updated distribution and production methods (Srai & Alinaghian, 2013).

The medicine supply chain is characterised by its complexity, highly customised nature and the unique role of the government who (in the UK) finance the majority of the costs. Another distinctive aspect of the chain is that the end customer (the patient) usually does not understand how the product/drug works, nor do they decide on the dosage or specific variety/brand. Demand therefore depends on the physicians/pharmacists who write prescriptions, not the consumers (Pedroso & Nakano, 2009).

Shah (2004) defines some of the supply chain challenges as increasingly long times to market, poor co-ordination within organisations, huge stock levels and exceptionally long cycle times. These issues result in value-added time frequently being in the region of 0.3-5% with material efficiency <10% (Narayana, et al., 2014). This is not just a problem for pharma, but also healthcare as the industry and its effective management are major drivers for the sector.

In order to address the several issues discussed within pharma and healthcare, a large amount of literature has focused on the adoption of e/digital supply chains within the industries. This has been the focus of papers including (Zhou, et al., 2015); (Narayana, et al., 2014); (Butner, 2010) and (Chen, et al., 2004). The latter defines an e-supply chain as a *"highly integrated supply chain with electronic links based on the Internet"*. Put simpler, it is the digitisation of supply chains through the adoption of the IoT, big data and digital advancements. The concept of digital supply chains is also described by Butner (2010) as being a smarter, more instrumented, interconnected, and intelligent supply chain which will thrive via interaction with customers throughout the entire product lifecycle, prioritising flexibility and visibility. It is emphasised by Zhou, et al. (2015) and Narayana, et al. (2014) that for the implementation of such supply chains, most themes in the literature principally stress the need for data driven business models to resolve issues of collaboration and coordination between players.

2.8. Research Gap Identification

The main gaps found in the academic literature relate to the role pharmaceutical companies may play in the digitisation of chronic illness treatment. There was little attention found on how emerging digital technologies and e-healthcare may better integrate pharma companies with patients and the healthcare sector, how such a connected system could be structured, or what value this could generate for each stakeholder. Similarly, limited literature exists that examines PSSs in the context of pharma and none explored how this combined with the IoT may influence business models and/or capture more value. Questions such as who would pay for the technology, who would own the data collected, who could use/share the data and what could be done with it were also found to be currently unanswered in literature.

3. Methodology

The research was specifically focused at the UK healthcare (NHS)/pharma industries. Both interviews and an online survey were conducted to gather primary data and develop a model.

3.1. Interviews

The interview process was aimed at gathering a broad range of perspectives across the industrial ecosystem (from pharma to device manufacturers). This enabled primary qualitative data to be gathered. Interviewees were selected based on compliance with the following criteria:

1. Currently in, or recently held, a senior (managerial/technical) role within the UK
2. Have relevant experience/knowledge of pharma, healthcare, wearable devices/technology, and/or regulatory bodies
3. Have an understanding of chronic disease(s) and respective treatment(s)

It was ensured that viewpoints from each of the major stakeholders within the industrial ecosystem were captured and analysed to decipher how best to inform the model. In total, ten interviews were completed. The details of the interviews are summarised in Table 3-1.

Table 3-1: Interview details summary

Interview	Organisation	Role	Focus	Criteria Met?
Pilot	Multi-national pharma	Senior manager	Pharma	✓
S1-1	Wearable-devices start-up	Lead engineer/ director	Wearables/tech	✓
S1-2	Independent pharma consultancy	Director/senior consultant	Pharma/pharmacy	✓
S1-3	NHS	Professor/GP	Healthcare	✓
S1-4	Multi-national pharma	Senior manager	Pharma SC	✓
S1-5	NHS/university	Clinical researcher/GP	Healthcare/device s/regulations	✓
S1-6	NHS/university	Professor/GP	Healthcare	✓
S1-7	Multi-national pharma	Senior manager	Pharma/devices	✓
S1-8	NHS/university	Professor/senior	Healthcare/tech	✓

		manager/GP		
S2	Multi-national pharma	Senior manager	Pharma	✓

The interview process consisted of three stages:

1. A pilot comprising of a single interview to test and refine question structure/wording
2. A data collection stage featuring eight interviews
3. A final (2nd) stage interview to validate the model developments

3.2. Online Survey

An online survey was developed and made active over a two month period from late-June to mid-August 2016. This build on the interviews by capturing data to represent the patients' perspective. It was targeted at the general public to avoid potential ethical issues of interviewing patients directly.

4. Results and Findings

4.1. Survey Results

In total, 122 responses were received from the online survey. From reviewing the data, it was found five respondents had not completed the form correctly and where consequentially excluded, leaving 117 for analysis.

The population included roughly an even split of males to females. Five suffered from diabetes and 16 suffered from other chronic illnesses. As chronic disease sufferers are generally older than the majority of the survey's demographic and only a limited number of respondents suffered from such a condition, it was acknowledged that the outcomes likely portray a generalised assessment of current patients. Based on this, the survey findings should be regarded as an insight into the perspective of patients in the near future, and not used to dictate how the system should operate at present.

4.1.1. Wearable-Devices

The data collected indicated that the majority of people would be happy to wear a data collection device, with only 2.5% stating otherwise (Figure 4-1). In terms of important features, comfort, light weight and non-invasiveness were found to be vital for such a device (Figure 4-1). From the various device options, the skin patch style (Lee, et al., 2016) was selected as the strong favourite (Figure 4-2). The option of a device automatically administering medication was also accepted by the majority of respondents (Figure 4-3).

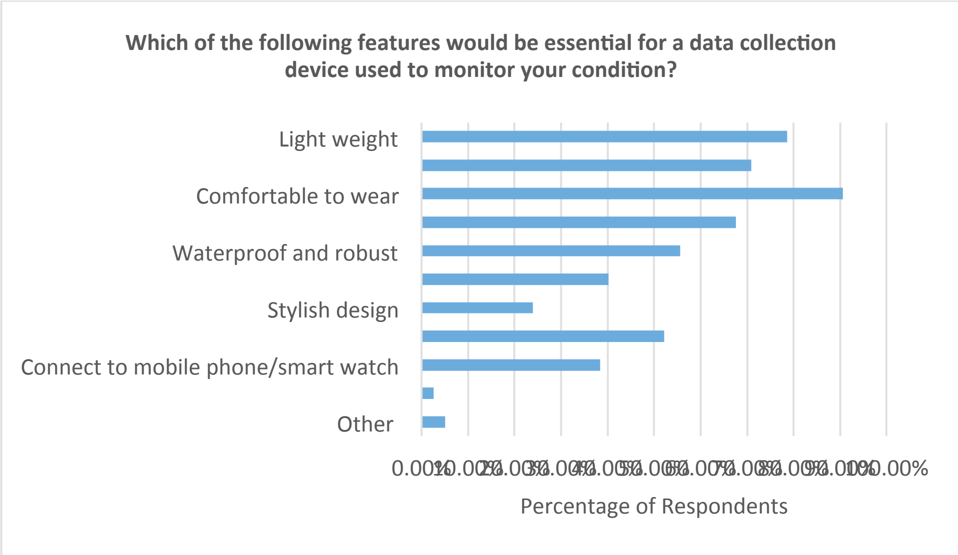


Figure 4-1: Device features

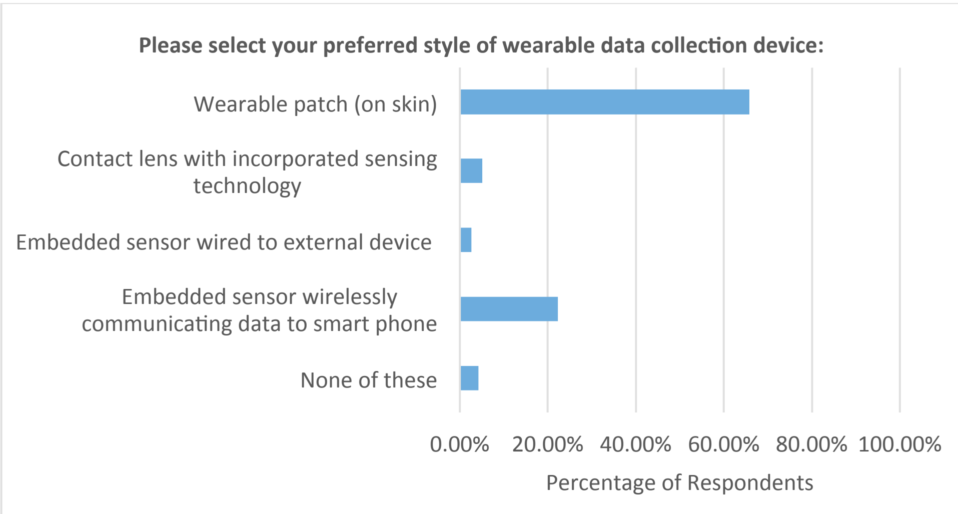


Figure 4-2: Preferred wearable-device

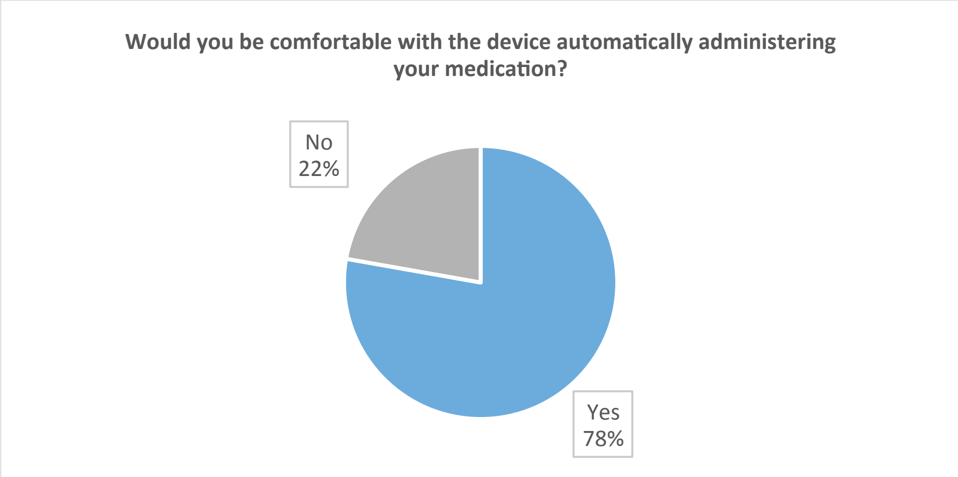


Figure 4-3: Automatic medication administration

4.1.2. Data Collection

With respect to key outcomes from data collection, respondents ranked improving their own conditions through better management/treatment and personalised medicine as the most vital. Ensuring anonymity of data was ranked third with respondents highlighting the importance that data could not be used by non-NHS organisations to identify them. Receiving a fee for their data was seen as by far the least important option (out of 7).

Figure 4-4&5 show that, in terms of data collection and use, the NHS was preferred considerately over the other options. One respondent added: *"I don't have much trust in pharmaceutical companies, so I wouldn't want them to access my data"*. This perception of pharma was a common theme observed throughout the survey and interview process.

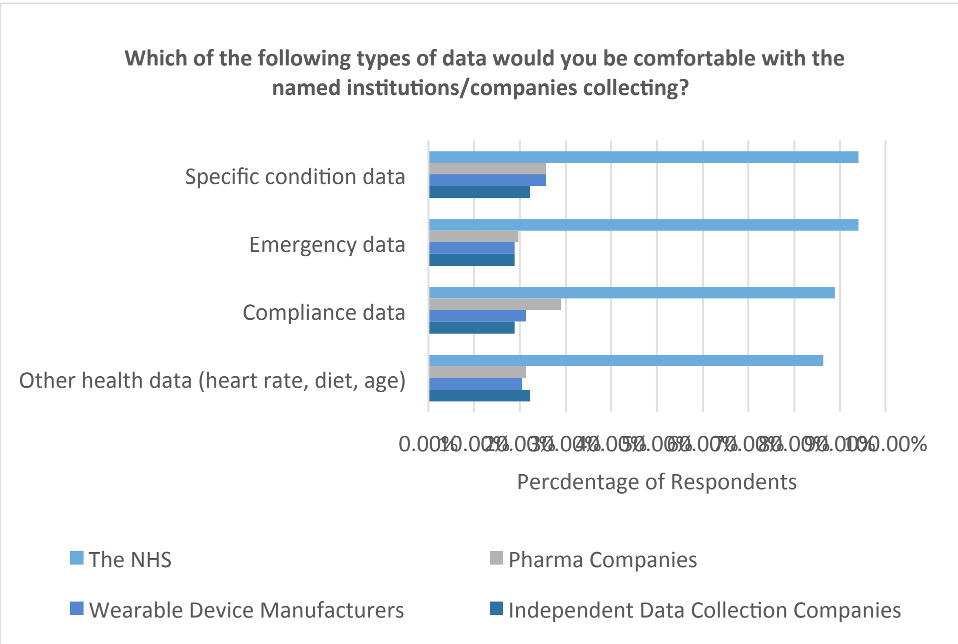


Figure 4-4: Data collection preferences

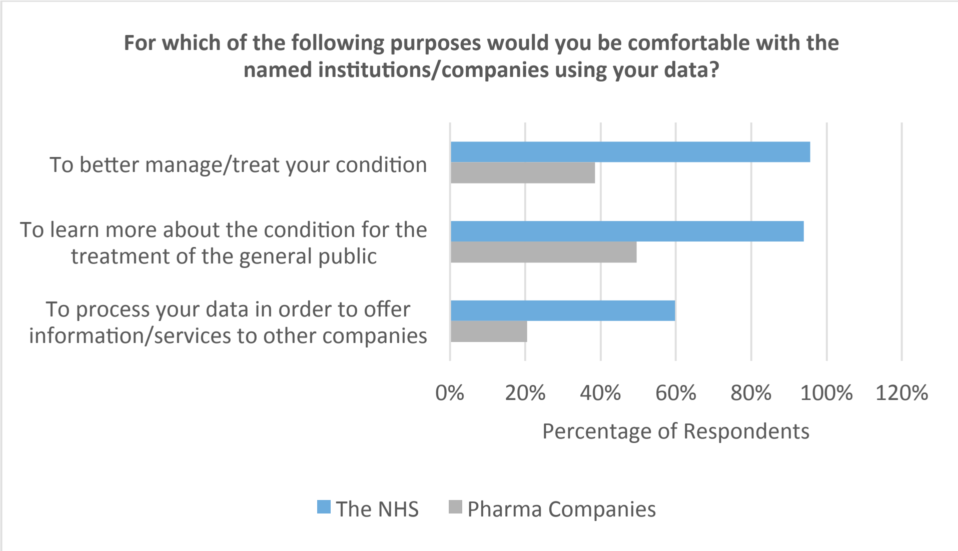


Figure 4-5: Data use preferences

4.1.3. Services and Financial Models

Figure 4-6 shows that the majority of respondents would be content receiving all of the remote data-based NHS services listed, however significantly less would feel the same if they were provided by pharmaceutical companies. Figure 4-7 demonstrates the bulk of respondents would be happy for the NHS to benefit financially from their data, but not the other listed organisations. Furthermore, 31% stated they would not be happy for any entity (including the NHS) to benefit financially from their data, stressing it should be used purely to improve peoples' health and not for profit.

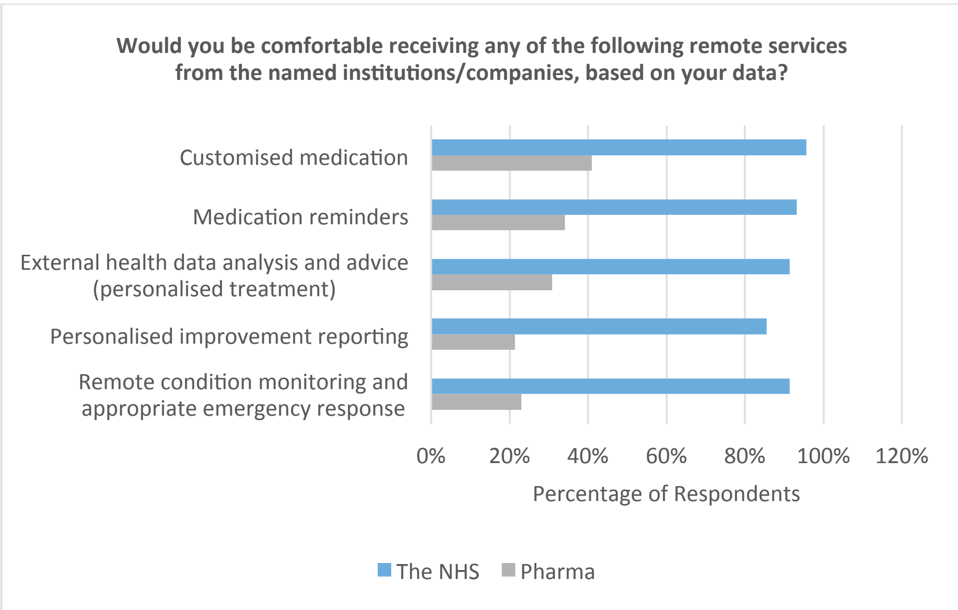


Figure 4-6: Remote services preferences

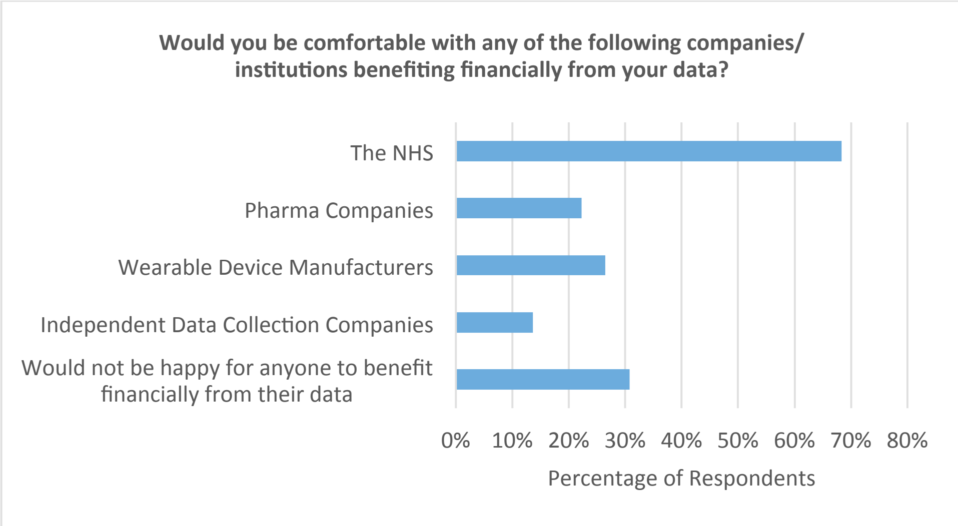


Figure 4-7: Companies financially benefiting

In Figure 4-8, it is shown that 95% of respondents would be comfortable receiving remote services provided by the NHS and 55% would pay a reasonable fee. Although this figure was lower for pharma, 71% of respondents still stated they would accept services from such companies and 35% would also be prepared to pay. Thus, only 29% stated they would not accept free or chargeable services from pharma in this particular question, contradicting with the results presented previously in Figure 4-6. Moreover, in Figure 4-9 it is shown that the majority of respondents would be comfortable with pharma partnering with the NHS to tackle chronic conditions, on the condition that they would not be charged for devices or services. It can be seen that less than 35% would be prepared to pay anything to help improve the treatment of their condition. Figure 4-9 also echoes the limited importance respondents expressed on receiving a fee for their data, previously captured in section 4.1.2.

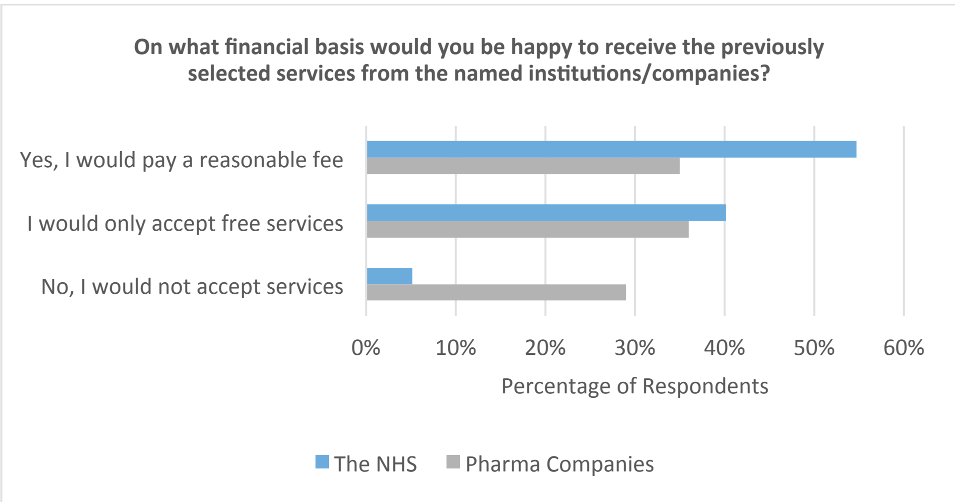


Figure 4-8: Payment for remote services

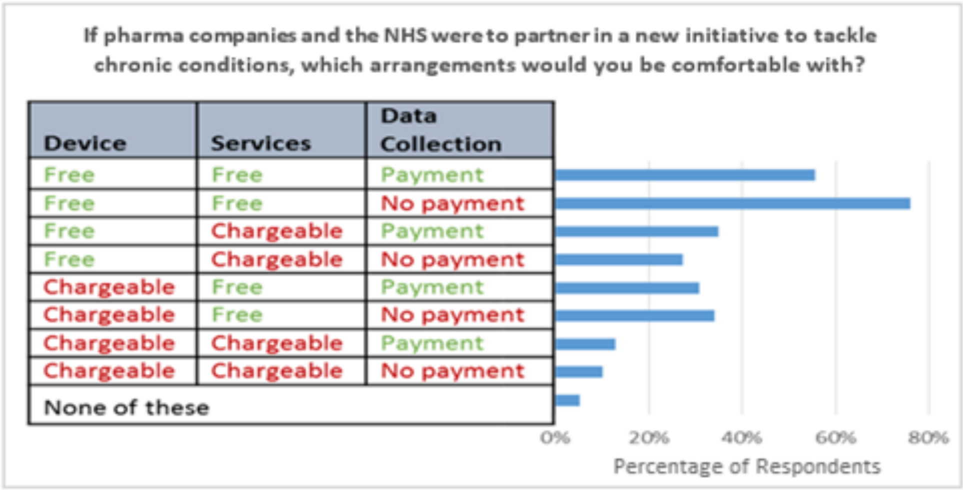


Figure 4-9: Finance model preferences

4.2. Interview Results

4.2.1. Disconnection of Pharma

The disconnect between pharmaceutical companies and patients, identified in the literature review, was echoed in the interviews. It was noted that, currently, patients only provide feedback to pharma during clinical trials and, discounting this, there is virtually no communication between them. This was mostly viewed, from the pharma perspective, as a great opportunity for emerging digital technologies to build more bi-directional relationships, enable the provision of remote services and reduce patient suffering.

In terms of a disconnect between pharma and the NHS, it was discovered that the two bodies actually currently work together relatively closely to develop drugs, negotiate acceptable prices and control supply levels. However, the issues of corruption, collusion and undercutting competition, as well as the fact *"their values and drivers are very different",* currently prohibits a more integrated relationship. Despite this, it was stressed "*there is a dialogue [with the NHS] to see how we [pharma] can work together for the benefit of the patient"*, facilitated via increased data collection/sharing.

4.2.2. Data Collection and Use

A common trend found was the NHS and pharma are both actively pushing the adoption of digital technologies. There was a general acceptance that technologies, such as wearable-devices and Apps, present significant value opportunities to patients and companies. Numerous examples of the NHS and pharma looking to/already partnering with tech companies were discussed. The need for pharma and the NHS to form partnerships with such companies was emphasised, particularly for the short term, to acquire their expertise and ability to innovate rapidly, and keep up with the industry. However, the difficulty of establishing said partnerships was underlined from the wearables perspective, listing bureaucracy, lack of available financial backing and the notoriously low acceptance of new, risky technology by the NHS as key issues.

The majority of parties interviewed expressed their desire to be at the centre of data collection. From the NHS perspective, it was heard that *"third parties are not needed, third parties add cost and complexity"* and healthcare would be best suited to provide data-based services. Likewise, from the perspective of pharma, collecting primary data was seen to be in their best interests to develop better drugs, improve supply chains and enable services such as personalised medication.

Data ownership was found to be a topic of uncertainty and disagreement. Nevertheless, the general consensus was patients' should own their data. It would therefore be the patients' right to decide who could access it and whether to charge for its collection. It was emphasised that patients are also generally protective of their data and are unwilling for it to be shared without permission. The case of the 'Care.data scandal' was cited as precedent (BBC News, 2014).

The additional clinical responsibility and implications of data collection were themes highlighted by the NHS. Interviewees expressed concerns that *"when you are monitoring the uploaded patient data, your duty of care to that patient is 24/7"* incurring additional staff training and emergency response requirements to use and act on data correctly – *"does the NHS have the capacity to be responsible?"*.

From the pharma perspective, it was stressed that simply gathering disease specific data would not be sufficient "*I can't see how just the reaction to the drug is enough to get huge value"*. Additional data, such as medication and activity details, would also be required to enable meaningful analysis. Data quality and reliability were seen as vital for analysis to be valuable and utilised safely.

4.2.3. Services

Both the NHS and pharma companies generally showed enthusiasm for adopting more data-based services. In one case, the example of the NHS in talks with a pharma company to establish a personalised medicine venture, based on selling cancer patients' data, was revealed. Pharma's desire of *"providing to the NHS more than just drugs"*, including consultation to help develop optimum personalised treatment plans for rarer conditions, was noted.

In the literature education is depicted as critically important, but often missing from available related mobile Apps (Taylor, 2015). Both the NHS and pharma expressed the interest of offering remote education services, with the newly developed 'My COPD' exemplified. My COPD is a free NHS 'self-management App', developed by a third-party, which will provide remote instruction on taking medication, reminders and monitor adherence. NHS professionals stressed the importance of said Apps to *"give the responsibility back to the patients and to support and educate them in terms of self-management"*. A suggestion from the pharma perspective would be to provide a mobile App/digital leaflet, accessed by scanning a unique code on a patient's medication with a smartphone. This could facilitate services, such as easily accessible disease and personalised medication information.

The point was raised that carers and family members are important stakeholders to consider as many chronically ill patients would rely on others to deliver the digital services. In addition, services focused on carers, such as remote support or alerts if patients where to need assistance, were recommended.

4.2.4. Finances and Payment Models

There was found to be a disparity in viewpoints in relation to finance models. An NHS professor suggested "*if you give someone something for free, they don't value it*", potentially resulting in improper use or damage. On the contrary, another professor stated *"you can't have a system that has such inequity of accessibility"*, only the rich can afford it. From the devices perspective, the majority of their income is from services and it would be infeasible to provide free devices (due to the large initial capital required). Nevertheless, the most common theme that emerged was, because the majority of chronic disease sufferers do not pay for prescriptions (due to their age and the nature of the NHS), patients should not be charged for devices or services. The general view expressed by pharma/NHS was that they would not be willing to pay patients for their data (outside of clinical trials) as this could be seen as unethical, particularly in the case of pharma.

A key theme stressed from the NHS's perspective was that of 'cost effectiveness'. It was emphasised that unless there is a clear value proposal for the NHS, then recommendation by NICE for incorporation would be doubtful. Furthermore, research studies/clinical trials partnerships between the NHS and universities would be mandatory to test new technologies and provide NICE with data on which to base their analysis. These partnerships, along with NICE and regulators (MHRA), would have to be funded via bodies separate to CCGs (such as the MRC or the NIHR).

4.2.5. Legislation and Data Security

A key theme communicated was the likely challenge of legislation in establishing a digitally connected ecosystem. It was argued that pharmacies will always have to play a role in the network due to laws governing drug prescription/supply. There was conflicted views expressed by representatives from pharma on whether said legislation could ever be changed to make pharmacies redundant. There was also repeated concerns and disparity over the legislation and regulations focused on how pharma may interact with patients, highlighting direct marketing and inducement as inevitable challenges.

Data security and confidentiality were recurring themes with all parties mindful of the potentially severe consequences of customer data being hacked, historically leading to law suits or fines.

4.2.6. Interview Findings Summary

The overarching theme found from analysing data collected through the interviews was the high level of disparity in viewpoints between stakeholders. This supports conclusions made in literature where it is argued these disparities exist even within individual industries (Harrington, et al., 2016). Consequentially, it was understood that designing a digitally connected value network will involve overcoming numerous challenges and conflicts of interest.

5. Model Development

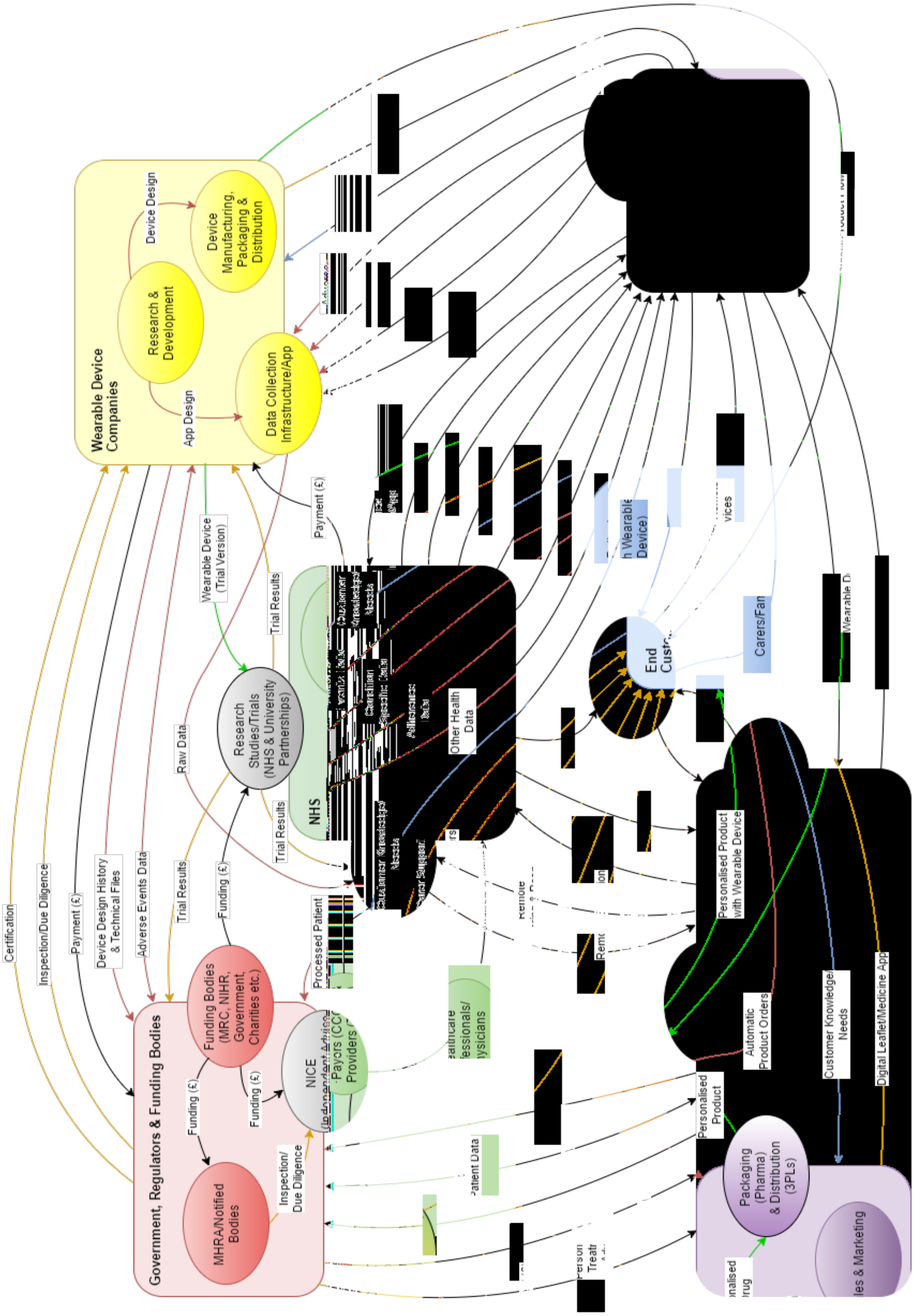
Further review of the literature on value chains suggested that as industrial systems become more complex, collaborative and service-based, the value network concept may be a more adequate modelling tool to use for such a complex, digital ecosystem (Peppard & Rylander, 2006). Based on the key findings and themes afforded through amalgamating the survey and interview data collection/analysis process, with further research, the framework and model proposed by (Allee, 2000) was adapted and extended to develop a comprehensive model (Figure 4-10) including additional stakeholders including the NHS, device/tech companies and regulators. It is proposed that this is the best solution, considering the various disparities identified from both industry and patients. The key developments made are detailed as follows.

5.1. NHS/Tech Company JV

The final model has been structured around a JV between the NHS and a (wearable) technology company, forming the central data collection and analytics entity. This was based on the publics' preference for the NHS to collect and analyse their data, while drawing on the necessary expertise and rapid innovation capability of an established technology company. A JV is the favoured approach here as it was emphasised that the NHS would not be able to move fast enough on its own to establish the infrastructure and analytical ability that such a partnership would enable. The data could be processed within this entity and distributed to healthcare professionals to enable the various remote services detailed in Figure 4-10. Data indicating any adverse events could be delivered to the MHRA, complying with regulations. In addition, data could also be sent to pharma companies, after obtaining individual patient consent. This could contain condition specific, medication reaction details and additional data required to enable pharma to ascertain value and effectively provide personalised medication. To address concerns expressed by the public, the data could be anonymised and encrypted, ensuring only the NHS/pharmacies could identify patients.

5.2. Inclusion of Automated Pharmacies

Automated (online) pharmacies were incorporated into the model to address legislation concerns and act as an intermediary between pharma, device companies and the patient. Patients could automatically receive personalised medicine and wearable-devices from said companies, in exchange for digital prescriptions (supplied via GPs), without requiring manual collection. An example of such a service is already offered free by 'PillPack'. PillPack organises and delivers patients' various medications, daily by the dose, and automatically takes care of refills. The automated ordering process could be facilitated via a replenishment request, sent from a wearable-device, to both pharmacy (PillPack) and pharma – enabling better sales volume forecasting.



Key:

Figure 5-1: Final model

5.3. Finance Models and Cost Effectiveness/Safety Analysis

Based on the views of industry, doctors and survey respondents, it is proposed that the supply of wearable-devices, personalised medication and the majority of remote services should be funded by the NHS. To justify the required expenses, the model highlights that the cost effectiveness of devices would first need to be calculated by NICE. The independent body could take data generated through research studies/trials (completed by university/NHS partnerships) and the MHRA, evaluate the value proposal and make the required recommendations to the NHS. It was emphasised that the devices could offer substantial value by reducing the cost/number of chronic-disease related emergencies and lower the demand on GPs/physicians, whilst, most importantly, reducing patient suffering.

Patients would not be paid for their data, but could be given the option in their initial GP prescription consultation to opt-out of the data collection scheme. It was also suggested that patients could be given a choice of device features (e.g. colour, design and functionality), potentially encouraging correct use/adherence. Personalisation and/or increased functionality could be offered for a fee.

To more clearly demonstrate how money flows within the network, the model's key was updated by separating finance (now shown as black links) from digital data flows (red links). This makes the model more informative for industry.

5.4. Incorporating Carers

Carers/family members have been incorporated into the model as, depending on the patient's condition, certain services may be received and delivered via these intermediaries. The model demonstrates both patients and carers could receive services/warnings simultaneously, potentially enabling carers to continuously monitor patient conditions and be their first point of care in emergencies.

5.5. Other Points

In addition to pharma providing digital Apps for personalised instructions and education, technology/wearables companies could also offer equivalent services for devices.

The possibility of re-distributed, continuous drug manufacture has been captured, demonstrating the potential for technologies, such as 3D printing, to enable localised and personalised medication manufacture (EPSRC, 2013).

Despite the majority of survey respondents expressing their comfort for wearable-devices both monitoring and automatically administering medication, the latter is not recommended. This is primarily due to concerns expressed in interview that this would cause devices to be classified as class 3, significantly increasing costs and regulatory burden.

Multi-layer analysis is rarely adopted in the literature, but is stressed by Gupta, et al. (2007) as vital to adequately understand how organisations operate within industrial ecosystems. The model was therefore structured in a multi-layered fashion, detailing both internal and external relationships within and between entities, demonstrating nuances in data flow.

6. Discussion and Conclusions

The conceptual model demonstrates the potential relationships between the main stakeholders identified in the ecosystem (pharma, the NHS, device/tech companies, regulators and patients). It maps the generic relationships (data/revenue streams, knowledge flows, goods and serviceable aspects) conceivable between stakeholders within the chronic care ecosystem, stimulated by emerging disruptive, digital technologies and re-distributed, continuous manufacturing processes.

The model falls short addressing some of the various disparities identified between stakeholders within the ecosystem. For instance, the model is structured with a partnership between the NHS and pharma where processed patient data may flow between them, facilitating the manufacture and distribution of personalised medicine. This is a core element of the network, yet based on the findings of the survey, the service may be infeasible due to conflicting public perceptions of pharma. Contradicting industrial viewpoints on factors, such as which body should be at the centre of data collection and whether pharmacies would still be required, will also lead to compromises having to be made. This raises the necessity for collaboration of industry players to work together to establish a mutually beneficial, connected network.

Bureaucracy, regulations and legislation within the ecosystem were highlighted as key constraints, limiting, for example, the prospect of a device automatically administering medication. These issues, in combination with NHS's emphasis on cost effectiveness, stress the difficulty for SMEs in entering the market. It also emphasises a need to partner with the NHS/MHRA early to understand their requirements and ensure a clear value proposal.

For a safe and secure system to ensure patients trust, data collected would need to be accurate, reliable and confidential, guaranteeing correct analysis and effective services. The responsibilities of ensuring safe infrastructure for collection, that sufficient resource would be available to deal with the data, and incentivising patients to use devices (correctly) would also be major challenges to overcome.

From an academic perspective, the model builds on the literature and provides a novel base for additional research. Academics could apply its generic architecture in specific chronic illnesses, different healthcare systems and, potentially, other industrial contexts. By way of an example, the model could be adapted for the food industry to monitor nutrition and/or allergies, enabling customers to control their diets and suppliers to improve the quality of their products.

The model also has implications for practice as it captures numerous serviceable aspects and potential new business models, previously unidentified in literature. It demonstrates its capacity to be used as a strategic planning tool, enabling managers to better position their companies for a more digital future. The model also helps simplify the inevitable complexity of a digital environment, capturing the rigorous regulations, constraints and barriers to entry for those within, or aspiring to enter the market.

7. Further Work

A key limitation in the study was potential ethical issues being raised by directly interviewing patients suffering from chronic disease. Further work could look to gain ethical approval, conduct additional interviews and acquire an accurate understanding of patients' perspectives. Furthermore, as the study is predominantly focused on human factors, partnering with academics from the social sciences in this process may afford deeper insights.

To further test the robustness of the model, additional work could focus on its application in a variety of chronic disease cases, or cell-based therapies where personalised treatment is vital. Monitoring airway swelling and whether inhalers are used correctly in COPD treatment could present challenges for the model and may be a thought-provoking case to investigate. It was also suggested the model may be better suited to a more privatised market, where adherence could be more easily incentivised. Thus, a case study of the US healthcare system is encouraged.

A significant opportunity to realise the value of the model would be to collaborate with industry. Such cross-disciplinary collaboration would ideally include academia working with both the NHS and a leading technology company to explore the proposed JV detailed in the model. This would facilitate a more in-depth, company specific case study to map out an implementation plan for the required data collection and RDM infrastructure.

Finally, further work should focus on implications the developed model and conceptual value network may have on future policy. New governmental standards will likely be necessary to control factors such as access to and security of patient, inventory and service level data, explore the role regulators may play, and define the responsibilities of each stakeholder. An investigation into future policy implications as a result of digitalisation is recommended.

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Customer Value Assessment in Pharmaceutical Industry

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Abstract

Clear understanding of how customers perceive value and what they value in specific product and/or service is crucial for effective business management and sustainable competitive advantage. However, definition and assessment of customer value is a challenging topic that has received much attention amongst practitioners and academics. This is particularly difficult for the pharmaceutical industry where defining who the customer is and what they value can vary widely. We discuss the concept of customer value and review critically different value assessment practices in order to propose a method for customer value assessment in pharmaceutical industry capable to address business decisions related to manufacturing process innovations.

Key words: Customer Value, Pharmaceutical industry, Customer Value Assessment

Understanding the role of Sustainability in Mergers & Acquisitions from the perspective of Supply Chain Management – *How green is the deal?*

Authors: Pavan Manocha, Jagjit Singh Srai and Mukesh Kumar

Keywords: Sustainability, Resource Efficiency, Mergers, Supply Chain Management and Operations

Topics: (1) Sustainability, (2) Mergers & Acquisitions, (3) Supply Chain Management

Abstract:

International manufacturing organizations face the challenge of implementing the UN 2030 Agenda for Sustainable Development and the Paris (COP21) commitments within the context of their global value networks. Networks that are increasingly fuelled by mergers and acquisitions (M&A), which in 2015 hit a record $4.28 trillion in deal value (Dealogic, 2015). While M&As produce mixed results, they fundamentally change the economic, social and environmental footprint of an organization, and its product supply chain. Merger synergies can change supply chain activities. In this paper we consider the factors that determine *how green is the deal?* and argue that sustainable supply chain management is a key consideration during pre-merger due-diligence, and in deal selection, assessment and execution. The objective of this paper is to test this argument by reviewing sustainability, mergers & acquisitions, and supply chain management literature published in peer-reviewed journals between 2010 and 2016. This paper's contribution lies in identifying the key theoretical questions relevant when assessing sustainability within the context of M&A.

Introduction:

At the United Nations Sustainable Development Summit on 25 September 2015, world leaders endorsed the 2030 Agenda for Sustainable Development. Two months later, at the Paris climate conference (COP21), 195 countries adopted the first-ever universal, legally binding global climate agreement. Today, international manufacturing organizations face the challenge of implementing these sustainability commitments within the context of their dynamic global value networks. Networks that are increasingly fuelled by mergers and acquisitions (M&A), which in 2015 hit a record $4.28 trillion in deal value (Dealogic, 2015).

M&A continues to be a highly popular form of corporate development (Cartwright and Schoenberg, 2006) as evidenced in 2016 by Pfizer & Allergan in their attempted $148.57 billion pharmaceutical merger, Dell's $63.4 billion acquisition of EMC, Kraft & Heinz's $40 billion merger and Unilever's acquisition announcement of eco-conscious brand Seventh Generation. Other sectors experiencing high M&A activity in 2016 are telecommunications, technology and energy (Dialogic, 2016).

The literature advances multiple theories, conceptual frameworks and motives for M&A (Trautwein, 1990). From the perspective of efficiency theory, M&As are planned and executed to achieve synergies. Three types of synergies have been distinguished, namely, financial, operational and managerial synergies. Synergies stem from combining operations of two companies to gain efficiency and scale to enhance competitiveness.

While M&As produce mixed results, they can fundamentally change the economic, social and environmental footprint of an organization, and its product supply chain. Merger synergies may change activities that span across the supply chain, including material sourcing, manufacturing, distribution and delivery. Supply chain management under M&A continues to be widely studied as a source of operational synergy (Gupta, 2012). In fact, enhanced supply chain performance represents the greatest cost reduction benefits-case, particularly in the context of horizontal mergers (Hard et al., 2005; Fumagalli and Motta, 2001; Inderst and Shaffer, 2007; and Cho, 2013). In this paper, we consider factors that would determine *how green is the deal?* and argue that sustainable supply chain management is a key consideration during pre-merger due-diligence, and in deal selection, assessment and execution (Srai et al, 2010).

The objective of this paper is to test this argument by systematically reviewing three bodies of literature: sustainability, mergers & acquisitions, and supply chain management published in peer-reviewed journals between 2010 and 2016, in order to understand the theoretical and organizational developments at the intersection of these fields. The research question is: *How might sustainable supply chain management considerations inform the M&A deal selection, assessment and execution processes?*

This paper is structured as follows: Theoretical Foundation: defines the theoretical arguments which link sustainability factors and M&A outcomes to supply chain performance. Approach: describes the research design and literature review results. Discussion: presents an analysis of the findings; and Conclusion: describes the implications, the theoretical contribution to theory, and informs future research direction.

Theoretical Foundation:

To establish the context for the literature review, key terms within the fields of sustainability, supply chain management and M&A, and their theoretical foundation are defined.

Sustainability

Sustainability issues are receiving increasing attention among businesses (Ahi and Searcy, 2013). Business sustainability initiatives are often conducted under a variety of titles, with "corporate sustainability" (Steurer et al., 2005) being amongst the most prominent. Sustainability is defined as *"a development that meets the needs of the present without compromising the ability of future generations to meet their own needs".* (Brundtland, 1997) While various definitions of sustainability exist, one central concept helping to operationalize sustainability is the triple-bottom line.

The triple-bottom line refers to a holistic evaluation of a firm's overall performance, measured by the integration of its environmental, social and economic sustainability (Elkington, 1998). Today, significant pressure is being placed on firms to improve their corporate social performance (CSP) and integrate environmental, social and governance (ESG) factors into their business practices, (Humphrey et. al., 2012).

In summary, key characteristics of sustainability include a focus on: *1) economic, 2) environmental, 3) social, 4) stakeholders, 5) volunteer, 6) resilience and 7) long-term outcomes (Ahi and Searcy, 2013).*

"More companies are managing sustainability to improve processes, pursue growth, and add value to their bottom-line rather than focusing on reputation alone" (McKinsey, 2012). Increasingly, researchers and practitioners in different fields are taking into account the impacts and implications of business sustainability on traditional assumptions and practices in their fields (Gimenez and Tachizawa, 2012). Supply Chain Management is one of these research areas.

Supply Chain Management

"A supply chain is a set of activities that span enterprise functions from the ordering and receipt of raw materials, manufacturing of products, through to the distribution and delivery to the customer" (Xu, 2010). One definition of Supply Chain Management (SCM) is *"the integration of these activities through improved supply chain relationships to achieve a sustainable competitive advantage"* (Li, 2007). However, the growing interest in SCM has led to the development of numerous definitions. Ahi and Searcy's (2013) literature review presents a synthesis of these definitions, and connects them back to theory in terms of the key characteristics exhibited. Theoretical concepts and key developments in the SCM literature are drawn from and include resource-based theory, stakeholder-theory, and transaction-cost economics theory (Sarkis, Zhu and Lai, 2011, Ahi and Searcy, 2013). Traditionally, SCM activities were primarily associated with material and information flow (Li, 2007). However, research on SCM has continued to broaden in scope (Burgess et.al., 2006) and today, includes aspects such as risk (Colicchia and Strozzi, 2012), resilience (Kumar et al, 2014), performance, (Hassini et. al., 2012) and integration (Fabbe-Costes and Jahre, 2007). There is also a growing emphasis on information flows, internal and external network relationships (Stock et. al., 2010), network synergy (Christodoulou, 2016), and supply network governance (Pilbeam et. al., 2012).

Mergers and Acquisitions

Mergers and acquisitions are often used interchangeably and referred to as M&As. There are slight differences between mergers and acquisitions by definition. Mergers have been defined as the combination of assets of two previously separate firms into a single new legal entity, and acquisitions imply that the assets of the acquired entity are absorbed by the acquirer (Ghauri and Buckley, 2003). M&As have been classified into horizontal, vertical and conglomerate according to the relatedness of the businesses, divided into domestic and international according to the location of their headquarters, and characterized as enabling network access or network efficiency according to their strategic objective for value creation. (Zhang, et. al., 2010). Theoretical concepts and key developments in the M&A literature are drawn from and include resource-based theory (James, 2002), efficiency, monopoly, raider, valuation, empire-building, process, disturbance theory (Trautwein, 1990), and stakeholder theory (Freeman, 1984). The efficiency theory views mergers as being planned and executed to achieve synergies (Porter, 1987; Friedman and Gibson, 1988). In general, the literature distinguishes between three types of synergies, namely, financial, operational and managerial (Trautwein, 1990). Per stakeholder theory, stakeholder relationship management is a critical in a successful post-merger integration, since up to 10% of customers can be lost during the post-merger integration process (Madhavan, 2005).

Approach:

This paper used a literature review research methodology (Fink, 2005, Cronin et al, 2008) to explore and systematically review three bodies of literature: sustainability, mergers & acquisitions, and supply chain management, with the aim of identifying the theoretical and organizational developments at the intersection of these fields, and to answer the research question: *How might sustainable supply chain management considerations inform the M&A deal selection, assessment and execution process?*

From a methodological point of view, the four-step process proposed by Mayring (2014) to collect, describe, select and evaluate the literature was used. The search for relevant publications was conducted as a structured keyword search, and limited to English-language peer-reviewed journals published between 2010 and 2016. Three sets of keywords were used, one for each body of literature. In SCM, the following keywords were used: "Supply Chain Management" and "Operations". In M&A, the keyword "merger" was used, and in Sustainability, keywords "Sustain*" and "Resource Efficiency" were used. This resulted in seven key word (A-G) combinations (reference legend below).

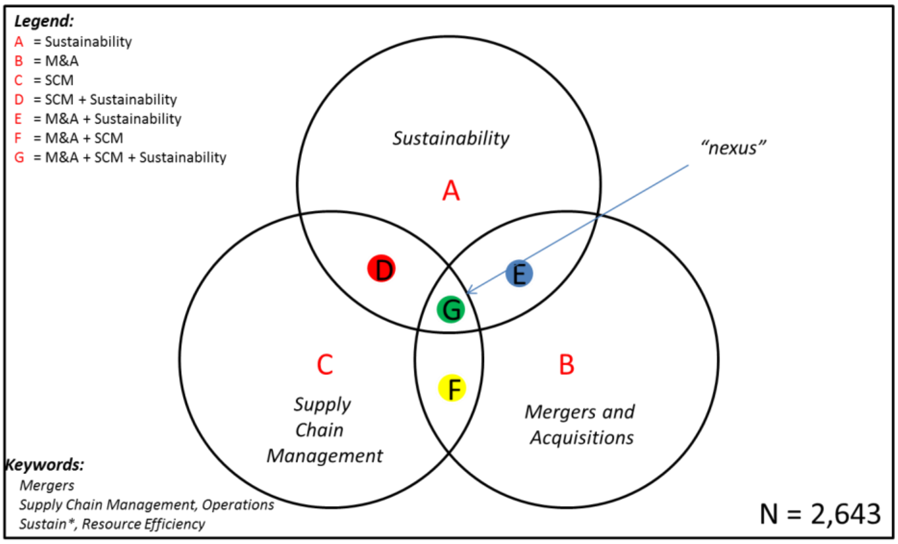

Figure 1: Preliminary dataset and focus area (A-G) definition

The scope of the search included title (A-C), abstract (D-F), and full-text (G) across the following six major databases: Elsevier (www.sciencedirect.com); Wiley (www.wiley.com); Scopus (www.scopus.com); Thomson Reuters (www.webofscience.com); JSTOR (www.jstor.com), and INFORMS (www.informs.com). During this first stage of the search, a 'preliminary' dataset of 2,643 articles were gathered.

Due to constrains of time and scale, the search was narrowed further so as to include only papers at the nexus (G) of the search (N=18), those available in Scopus (N=1859) with citations greater than one-hundred (N=15), and those published in 'four-star' journals, as ranked in the ABS Academic Journal Guide (2015) in the fields of 1) general management, ethics and social responsibility, 2) operations research and management science, 3) operations and technology management, and 4) strategy (N=34). Taking this further delimitation into consideration and accounting for duplication, a 'final' dataset of 60 papers were identified.

In the first step of the evaluation, descriptive dimensions were used to classify and establish an understanding of: (1) the distribution of publications across the time period, (2) the journals in which these papers were published, and (3) the most cited papers, authors and journals. Additionally, using the delimitated 'final' dataset (N=60) as the basis for evaluation, the research aim is to understand (4) which methodologies are applied, (5) what are the dominant theories used, and (6) which theoretical framework(s) are advanced. The literature was analysed and the findings are presented in the summary Tables 1 – 12.

Focus	Database						Total
	JSTOR	INFORMS	SCOPUS	SD	WoS	Wiley	
(A) Sustainability	8	6	90	122	52	5	283
(B) Mergers & Acquisitions	6	7	665	5	3	6	692
(C) Supply Chain Management	16	6	889	284	132	2	1329
(D) Supply Chain Management + Sustainability	11	0	144	10	83	2	250
(E) Mergers & Acquisitions + Sustainability	0	0	28	0	0	1	29
(F) Mergers & Acquisitions + Supply Chain Management	1	1	34	2	4	0	42
(G) Mergers & Acquisitions + Sustainability + Supply Chain Management	5	1	9	2	0	1	18
Total	**47**	**21**	**1,859**	**425**	**274**	**17**	**2,643**

Table 1: Preliminary Dataset (N=2,643)

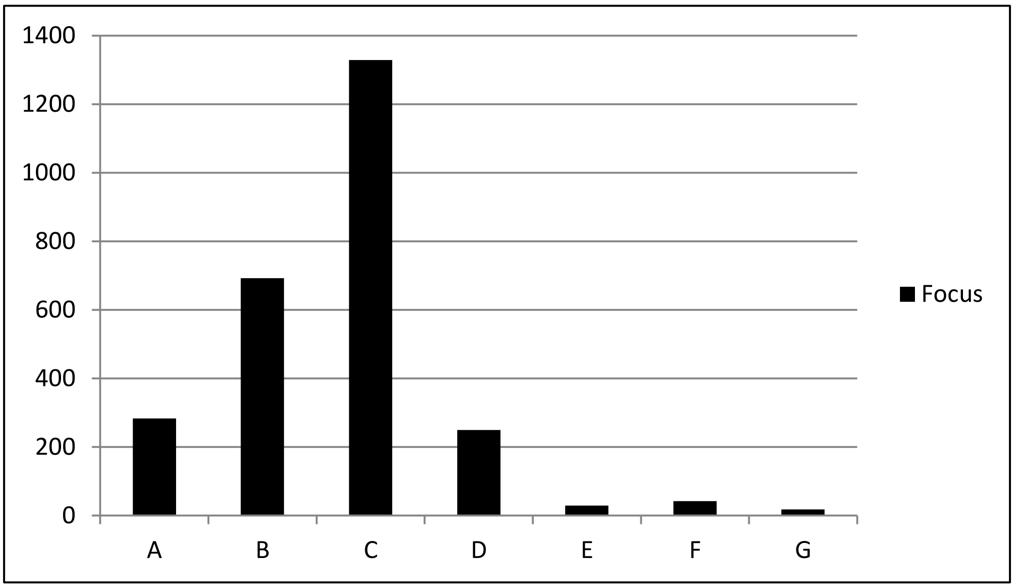

Table 2: Literature Distribution by Focus Area (A-G), (N=2,643)

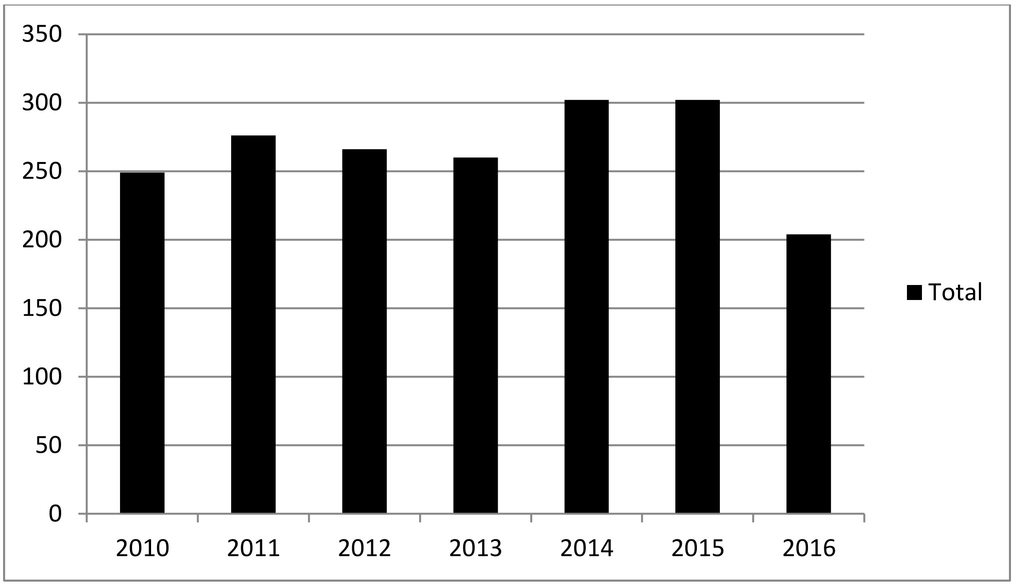

Table 3: Distribution of Publications 2010-Present (SCOPUS, N=1859)

4* ABS Ranked Journal Name	2010	2011	2012	2013	2014	2015	2016	Total
Journal of Operations Management	2	5	1		1	2	2	13
Management Science	5				2	2		9
Operations Research		3				1	1	5
Strategic Management Journal	2		1		1	1		5
Journal of Management	1						1	2
	10	8	2	0	4	6	4	34

Table 4: Subset of SCOPUS dataset containing 4* ABS Ranked Journals, by Year (N=34)

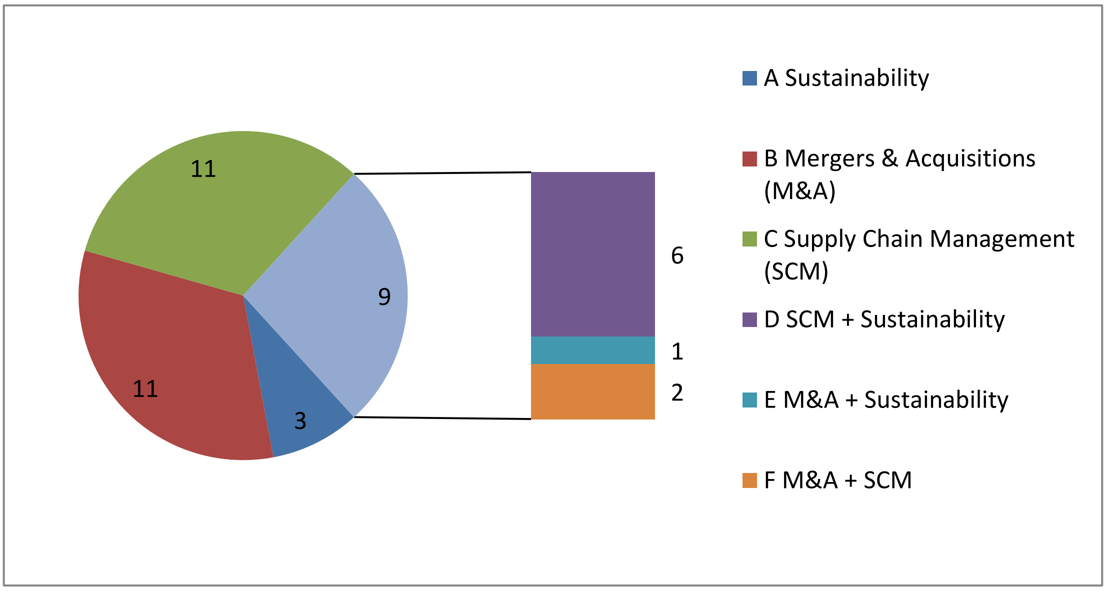

Table 5: Subset of SCOPUS dataset containing 4* ABS Ranked Journals, by Focus Area (N=34)

Focus	Author(s)	Title	Year	Journal	Citations#
C	Sarkis J., Zhu Q., Lai K.-H.	An organizational theoretic review of green supply chain management literature	2011	International Journal of Production Economics	352
D	Nyaga G.N., Whipple J.M., Lynch D.F.	Examining supply chain relationships: Do buyer and supplier perspectives on collaborative relationships differ?	2010	Journal of Operations Management	200
C	Gold S., Seuring S., Beske P.	Sustainable supply chain management and inter-organizational resources: A literature review	2010	Corporate Social Responsibility and EM	151
C	Tang O., Nurmaya Musa S.	Identifying risk issues and research advancements in supply chain risk management	2011	International Journal of Production Economics	149
B	Makri M., Hitt M.A., Lane P.J.	Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions	2010	Strategic Management Journal	144
A	Börjesson P., Tufvesson L.M.	Agricultural crop-based biofuels - Resource efficiency and environmental performance including direct land use changes	2011	Journal of Cleaner Production	140
C	Tate W.L., Ellram L.M., Kirchoff J.F.	Corporate social responsibility reports: A thematic analysis related to supply chain management	2010	Journal of Supply Chain Management	130
C	Testa F., Iraldo F.	Shadows and lights of GSCM (green supply chain management): Determinants and effects of these practices based on a multi-national study	2010	Journal of Cleaner Production	126
C	Wu Z., Pagell M.	Balancing priorities: Decision-making in sustainable supply chain management	2011	Journal of Operations Management	122
C	Xu L.D.	Information architecture for supply chain quality management	2011	International Journal of Production Research	113
C & D	Ahi P., Searcy C.	A comparative literature analysis of definitions for green and sustainable supply chain management	2013	Journal of Cleaner Production	112
C	Green Jr. K.W., Zelbst P.J., Meacham J., Bhadauria V.S.	Green supply chain management practices: Impact on performance	2012	Supply Chain Management	110
C	Thun J.-H., Hoenig D.	An empirical analysis of supply chain risk management in the German automotive industry	2011	International Journal of Production Economics	107
C	Brandenburg M., Govindan K., Sarkis J., Seuring S.	Quantitative models for sustainable supply chain management: Developments and directions	2014	European Journal of Operational Research	106

Table 6: SCOPUS Articles where number of citations > 100; (N=15); grey-highlighted are the subset of 4*ABS Ranked Journals (2015)

Focus	Database						Total
	JSTOR	INFORMS	SCOPUS	SD	WoS	Wiley	
(A) Sustainability	-	-	4	-	-	-	4
(B) Mergers & Acquisitions	-	-	12	-	-	-	12
(C) Supply Chain Management	-	-	22	-	-	-	22
(D) Supply Chain Management + Sustainability	-	-	8	-	-	-	8
(E) Mergers & Acquisitions + Sustainability	-	-	1	-	-	-	1
(F) Mergers & Acquisitions + Supply Chain Management	-	-	2	-	-	-	2
(G) Mergers & Acquisitions + Sustainability + Supply Chain Management	5	1	9	2	0	1	18
Total	**5**	**1**	**58**	**2**	**0**	**1**	**67**

Table 7: Final Dataset (N=67), includes duplicate references

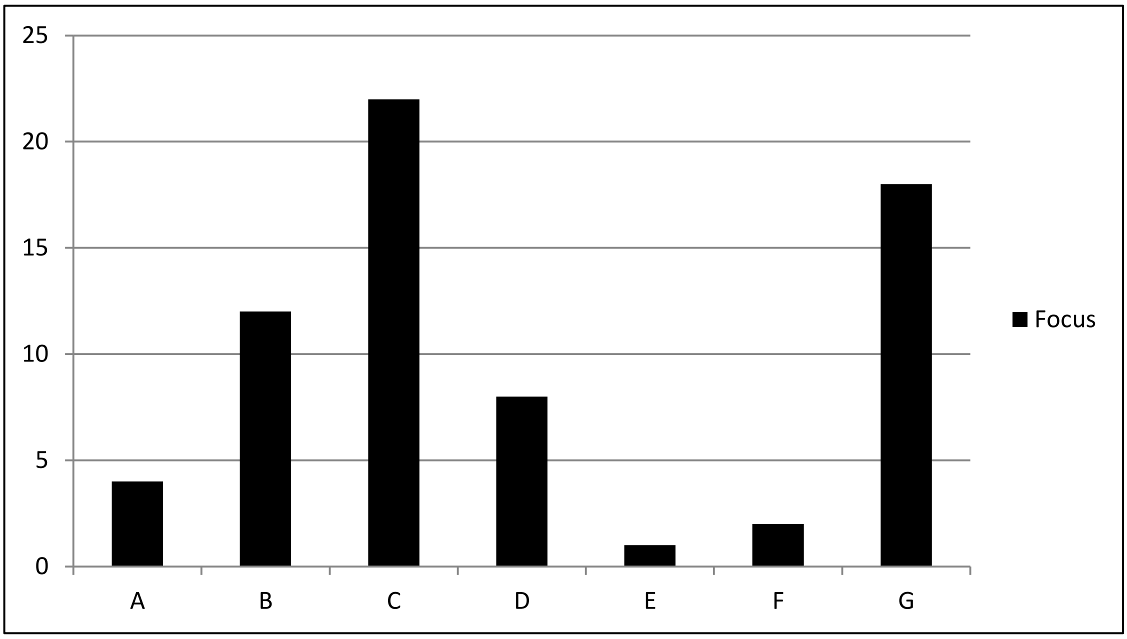

Table 8: Literature Distribution by Focus Area (A-G), (N=67), includes duplicate references

Journal Name	2010	2011	2012	2013	2014	2015	2016	Total
Journal of Operations Management	2	5	1		1	2	2	13
Management Science	6				2	2	1	11
Operations Research		3				1	1	5
International Journal of Production Economics		3				2		5
Strategic Management Journal	2		1		1	1		5
Journal of Cleaner Production	1	1		1				3
Advances in Mergers and Acquisitions			1	1				2
Journal of Management	1						1	2
European Journal of International Management	1							1
Journal of Supply Chain Management	1							1
Research in Transportation Business				1				1
Supply Chain Management			1					1
Decision Sciences			1					1
Transportation Research Part E			1					1
Production and Operations Management							1	1
European Journal of Operational Research					1			1
International Journal of Production Research		1						1
Strategic Management Journal	1							1
International Business and Management					1			1
Corporate Social Responsibility and Environmental Management	1							1
Administrative Science Quarterly	1							1
Journal of Global Information Management				1				1
	17	**13**	**6**	**4**	**6**	**8**	**6**	**60**

Table 9: Final dataset, all referenced journals, by Year (N=60)

Reference	Focus / Database						
	A	B	C	D	E	F	G
Ahi P., Searcy C., A comparative literature analysis of definitions for green and sustainable supply chain management, Journal of Cleaner Production, 2013.	-	-	Scopus	Scopus	-	-	-
Goranova M., Dharwadkar R., Brandes P., Owners on both sides of the deal: Mergers and acquisitions and overlapping institutional ownership, Strategic Management Journal, 2010.	-	Scopus	-	-	-	-	JSTOR
Haleblian J., McNamara G., Kolev K., Dykes B.J. Exploring firm characteristics that differentiate leaders from followers in industry merger waves: A competitive dynamics, Strategic Management Journal perspective, 2012.	-	Scopus	-	-	-	-	Wiley
Makri M., Hitt M.A., Lane P.J. Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions, Strategic Management Journal, 2010.	-	Scopus (x2)	-	-	-	-	JSTOR
Nyaga G.N., Whipple J.M., Lynch D.F. Examining supply chain relationships: Do buyer and supplier perspectives on collaborative relationships differ? Journal of Operations Management, 2010.	-	-	-	Scopus (x2)	-	-	-
Wu Z., Pagell M., Balancing priorities: Decision-making in sustainable supply chain management, Journal of Operations Management, 2011.	-	-	Scopus (x2)	-	-	-	-

Table 10: Duplicate references within final dataset, (N=7)

Journal Name	2010	2011	2012	2014	2015	2016	Total
Journal of Cleaner Production		1		1		3	5
Asia Pacific Management Review	1			1			2
Global Business and Organizational Excellence	2						2
Journal of International Management				1		1	2
Journal of the International Academy for Case Studies	2						2
Computers and Operations Research						1	1
Engineering, Construction and Architectural Management	1						1
European Journal of International Management	1						1
Information Systems Research					1		1
International Business Management					1		1
International Journal for Housing Science and Its Applications						1	1
International Journal of Business and Systems Research	1						1
International Journal of Intelligent Information Technologies	1						1
International Transactions in Operational Research			1				1
Journal for Global Business Advancement				1			1
Journal of Business Strategy	1						1
Production and Operations Management						1	1
Research Policy			1				1
Service Industries Journal		1					1
Strategic Management Journal					1		1
	10	2	2	4	3	7	28

Table 11a: Focus (E) M&A and Sustainability (SCOPUS)

Journal Name	2010	2011	2012	2013	2014	2015	2016	Total
International Journal of Production Economics	1		1			3	1	6
International Journal of Production Research	1	1	1		1	2		6
European Journal of Operational Research	1				1			2
Decision Sciences			1					1
European Journal of International Management	1							1
Industrial Management and Data Systems							1	1
International Food and Agribusiness Management Review						1		1
International Journal of Critical Infrastructure Protection							1	1
International Journal of Innovation Science						1		1
International Journal of Services and Operations Management	1							1
International Journal of Technology Intelligence and Planning					1			1
Journal of Business Logistics					1			1
Journal of Cases on Information Technology		1						1
Journal of Cleaner Production				1				1
Journal of Operations Management		1						1
Journal of Product Innovation Management				1				1
Management Science	1							1
Manufacturing and Service Operations Management	1							1
Packaging News		1						1
Production and Operations Management							1	1
Research Technology Management			1					1
Technological Forecasting and Social Change		1						1
Transportation Research Part E: Logistics and Transportation Review			1					1
	7	5	5	2	4	7	4	34

Table 11b: Focus (F) M&A and Supply Chain Management (SCOPUS)

Theory	Definition	References
Resource Based View (RBV)	The resource-based model of competitive advantage suggests that competitive advantage may be sustained by harnessing resources that are valuable, rare, imperfectly imitable, and non-substitutable (Barney, 1991).	Sarkis J., Zhu Q., Lai K.-H. (2011); Gold S., Seuring S., Beske P. (2010); Wu Z., Pagell M. (2011)
Transaction Cost Economics	Transaction cost economics focuses on how much effort and cost is required for two entities, buyer and seller, to complete an activity (economic exchange or transaction) (Williamson, 1981).	Sarkis J., Zhu Q., Lai K.-H. (2011); Nyaga G.N., Whipple J.M., Lynch D.F. (2010)
Stakeholder Theory	Stakeholder theory suggests that companies produce externalities that affect many parties (stakeholders), which are both internal and external to the firm. Externalities often cause stakeholders to increase pressures on companies to reduce negative impacts and increase positive ones (Sarkis et al., 2011).	Sarkis J., Zhu Q., Lai K.-H. (2011)
Agency Theory	Agency theory focuses on scenarios that one entity, the principle, authorizes a second, the agent, to act on the principle's behalf (Eisenhardt, 1989).	Tang O., Nurmaya Musa S. (2011); Goranova, M., Dharwadkar, R., Brandes, P. (2010)
Five-Capitals Framework (TBL Theory)	Natural capital is defined as any stock or flow of energy and matter that yields valuable goods and services (Porritt, 2007).	Tate W.L., Ellram L.M., Kirchoff J.F. (2010); Wu Z., Pagell M. (2011)

Table 12: Dominant Theories

Discussion

The literature at the intersection of sustainability, M&A and supply chain management published in 4* ABS-ranked peer-reviewed journals between 2010 and 2016 is limited (G), with only 18 citations (Table 7), thereby supporting the conclusion that the integration of these fields represents a niche worthy of research.

The 4* ABS journals which appear to be most relevant are the *Journal of Operations Management* and *Management Science* (Table 9). Table 11 (a and b) defines the publication volume across all peer-reviewed journals and highlights a broader sub-set of literature at the intersection of M&A and sustainability (E) and M&A and supply chain (F). Taking into account this broader sub-set, relevant literature has been published in the *International Journal of Production Economics, International Journal of Production Research* and *Journal of Cleaner Production.*

The final dataset includes action research, literature reviews, case-study based grounded theory, and conceptual development papers. Resource-based view, transaction economics and the triple-bottom line (including the Five-Capitals Framework, Figure 2) are some of the dominant theories advanced by the literature (Table 12).

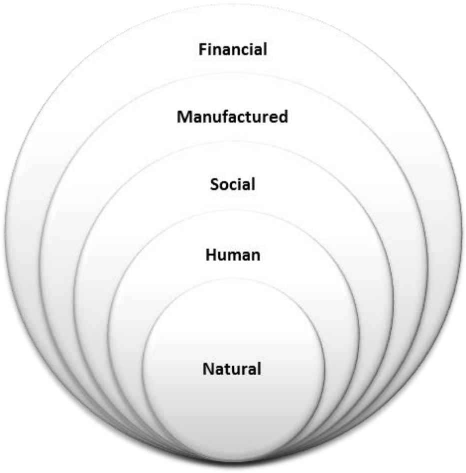

Figure 2: Five-Capitals Theoretical Lens

Sustainability and Supply Chain Management

The literature at the intersection of sustainability and supply chain management (D) is limited, where only seven papers were identified. However, within the field of supply chain management (C), a larger population of twenty papers were identified, several of which have references to sustainable supply chain management (Gold S., Seuring S., Beske P., 2010), green supply chain management practices (Green Jr. K.W., Zelbst P.J., Meacham J., Bhadauria V.S., 2012) and corporate social responsibility (Tate W.L., Ellram L.M., Kirchoff J.F., 2010).

Ahi and Searcy (2013) defined sustainable supply chain management as:

> *"The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organizations over the short- and long-term".*

Furthermore, Ahi and Searcy (2013) identify seven business sustainability characteristics: *economic, environmental, social, stakeholder, volunteer, resilience and long-term focus*. The literature highlights the fact that firms are increasingly under pressure from stakeholders to incorporate the triple-bottom line of social, environmental and economic responsibility considerations into operations and supply chain management strategies (Tate, Ellram and Kirchoff, 2010). Carter and Rogers (2008) provide a theoretical framework to apply the triple-bottom line in defining sustainable supply chain management. Tate, Ellram and Kirchoff (2010) analysis of CSR reports identified ten-major themes which are relevant to sustainability and supply chain management.

Themes Relevant to SCM (Tate, Ellram and Kirchoff, 2010)				
1) Supply Chain	2) Institutional Pressure	3) Community Focus	4) Consumer Orientation	5) External Environment
6) Risk Management	7) Measures	8) Energy	9) Healthcare	10) Green Building

Figure 3: Summary of CSP Themes and Relationship to SCM

Gold et. al. (2010) in their highly cited literature review tests the framework for Sustainable Supply Chain Management (SSCM) advanced by Bowen et. al. (2001) and conceptualizes a more holistic framework for SSCM, which draws upon resourced-based theory and its extension, the relational view, highlighting *collaboration* as a core competency in delivering SSCM. They suggest that while the literature makes a case that competitive advantages maybe gained by adopting environmental and sustainable strategies, "it should be noted that the financial necessity dictates to all companies that environmental and social issues are adequately arranged with economic viability as the third dimension of sustainability" (Hahn and Scheemesser, 2006).

Tang and Musa's (2011) review on Supply Chain Risk Management (SCRM) provides a classification of potential supply chain risks associated with material, cash and information flows. They present a linkage to sustainability, in the context of environmental degradation and awareness as a supply chain risk and function of material flow. Their work draws upon agency theory and the opportunity to understand the inter-relationships between supply chains, and to maintain a system perspective in management.

The case for adopting Green Supply Chain Management (GSCM) has some overlap with merger motives. Supply chain orientated environmental management is development not just as an ad-hoc operational response to external pressures, but a key-element of a strategic vision, aimed at pursuing better environmental and commercial results (mostly in a synergistic way). These are implemented to pursue cost-reduction and to increase efficiency (Corbett and DeCroix, 2001).

In support of this argument, Testa and Iraldo (2010) cite the three most diffused strategic approaches that are able to favour the adoption of GSCM practices as *i) reputation-led, ii) efficiency-led and iii) innovation-led.* In their study, GSCM does not emphasize a positive correlation with firm profitability and competitiveness.

Wu and Pagell (2011) case study of exemplar companies in SSCM and environmental sustainability addresses decision-making, specifically, the trade-off between short-term profitability and long-term environmental sustainability. Their findings illustrate that decision making comes down to a firm's values and objectives (operating principles), and as such, have identified four "postures": *i) the environment first posture, ii) the equal footing posture, iii) the opportunity first posture and iv) the community first posture.* The commitment of the workforce is also a key component if mitigating trade-offs and creating a unique supply chain.

Brandenburg et. al. (2014) review of SSCM literature includes a summary of sustainability factors beyond the triple-bottom line. For instance, in their literature review summary, they cite specific economic, environmental and social metrics (Table 13).

Sustainability factors

Factor	**Category**	**Metric**
Economic	Micro-economic	Cost, profitability, and revenue (Lovric, et. al., 2012)
	Macro-economic	Gross domestic product or growth rate (Agrell et. al., 2004). Labor productivity, market concentration, or import dependency (Yakovleva et. al., 2014)
Environmental	Input-orientated factors	Renewable energy sources, natural resources, water and energy consumption and water quality (Feng et. al., 2007)
	Output-orientated factors	Waste and pollution, environmental impacts of construction, normal operations and failure (Dey, 2006)
Social	Internal influences	Wages, employees or employment gender ratios (Yakovleva, et. al., 2011)
	External influences	Customer needs and requirements, social acceptance and contribution to employment, or population growth (Feng et al., 2007)

Table 13: Sustainability Factors (Brandenburg et. al., 2014)

Mergers and Acquisitions for Supply Chain Competitiveness

Besides the active research in supply chain and M&A, there are very few papers that integrate both issues. Much of the literature advances the notion that non-financial measures, such as environmental performance, have gained importance, given the increasing recognition of sustainable development in our society. Traditional finance theory informs us that an organization's sole mandate is to maximize shareholder value. However, today, there is significant pressure being placed on firms to improve their corporate social performance (CSP) and integrate sustainability, sometimes defined as environmental, social and governance (ESG) factors into their business practices (Humphrey et. al., 2012). There is also a widely held view amongst ESG investors that industry-specific criteria provides additional information and should be included in any analysis of CSP. The mainstreaming of ESG analysis is also evident in current mergers and acquisitions (European Sustainable Investment Forum, 2009). This demand is driven by a mixture of investor reputation, beneficiary pressure and an evolving view on fiduciary duty.

Typical due diligence processes in M&As commonly focus on financial health (Hitt et. al., 2001) and rarely try to identify special knowledge stocks held by targets (Makri, Hitt and Lane, 2010). The process of integrating knowledge complementarities to develop novel inventions that provide such value represents a form of what Helfat et al., (2007) refer to as "asset orchestration". Many of the theories and constructs used in prior research and practice to evaluate the effectiveness of M&As are entrenched in the old, manufacturing-dominated competitive environments. Makri, Hitt and Lane (2010) suggest that in high-technology M&As, the integration of science and technology knowledge may serve as a better indicator of private synergy than assessing relatedness in terms of firms' market and product portfolios.

The literature indicates that the strategic rationale for mergers has been organized around four different "competitive efforts": *improving competitive positioning, extending product portfolios, leveraging economies of scale or re-defining scope and industry* (Sorensen, 2000; Langabeer, 2003). The methodological framework for international M&A value creation advanced by Srai et. al. (2010) establishes our context upon which to frame the argument that sustainable supply chain management is a key consideration during pre-merger due-diligence, and in deal selection, assessment and execution (Figure 4).

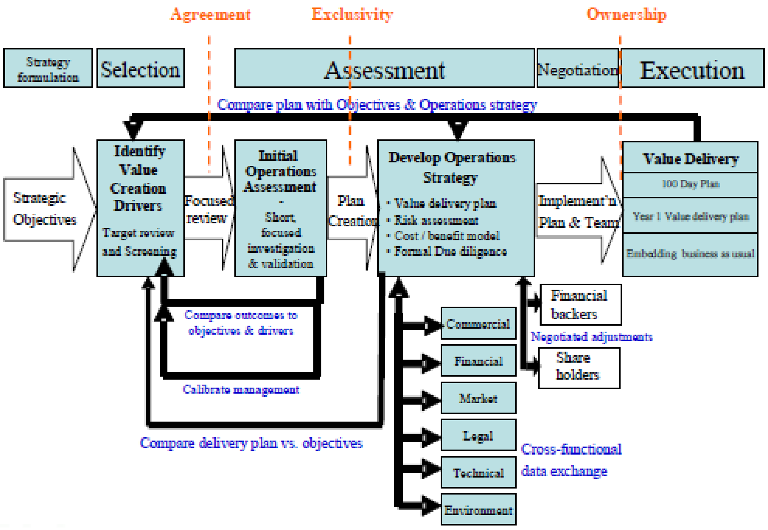

Figure 4: Business and Operational Stages in International M&A (Srai et. al., 2010)

Integration of Sustainable Supply Chain Management within the M&A process

Applying the methodological framework advanced by Srai et. al., (2010) against the thematic analysis of supply chain management advanced by Tate, Ellram and Kirchoff (2010), a conceptualization of the key theoretical questions relevant when assessing sustainability within the context of M&A can be suggested (Figure 5).

Operational Stages (Srai et, al., 2010)	**Sustainability Factors (SSCM)** **(Brandenburg et. al., 2014)**					
	Economic		Environmental		Social	
	Micro-economic	*Macro-economic*	*Input-orientated factors*	*Output-orientated factors*	*Internal influences*	*External influences*
Strategy Formulation	1	3	1	1	2	3, 4
Selection	1	3	1	5	9, 10	5
Assessment	1, 8	6	1	1, 6	2	2, 3, 5, 6
Negotiation*			6	6, 7		
Execution	1	3	1, 6, 7	1, 7, 10	2	4, 5

Figure 5: Conceptualization of the key theoretical questions relevant when assessing sustainability within the context of M&A

Conclusion

This paper reviewed three bodies of literature: sustainability, mergers & acquisitions, and supply chain management, and posed the research question*: How might sustainable supply chain management considerations inform the M&A deal selection, assessment and execution processes?* The findings suggest sustainable supply chain management considerations can significantly inform strategy formulation, and M&A deal selection, assessment, negotiation and execution, as a source of economic, environmental and social synergy or (dis)-synergy in the following ways:

1) From the perspective of strategy formulation and deal selection, the literature identifies an opportunity for input / output orientated supplier management, sourcing practices and community awareness considerations.

2) Social considerations have been identified that can influence M&A assessment and pre-merger due-diligence; these include environmental compliance and an assessment of corporate social responsibility across the supply chain network.

3) Negotiation and deal pricing considerations may include an assessment of all supply chain risks. Risks should be assessed, quantified, mitigated, priced and reflected in the overall deal economics.

4) Finally, from the perspective of execution, measurement and management of environmental reporting, energy efficiency and process safety performance have been identified as additional sources of post-merger integration value.

Further research is required to extend the dataset of peer-reviewed literature. Industry-level differences also need to be further explored.

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The Emerging Market Manufacturing Business Groups (EMBGs) and the Interplay between Innovation in Environmental Sustainability, Digitalization, Internationalization and Corporate Governance Structures: The Case of Turkish Holding Companies

Abstract

The purpose of this research is to explore the Emerging Market Manufacturing Business Groups' (EMBG's) innovation processes through their internationalization activities and the interplay between innovation in environmental sustainability, digitalization, networks, and corporate governance structures. This study focuses on the business dynamics of manufacturing Turkish Business Groups, namely Turkish Holding Companies. It gives a clear illustration of how manufacturing can be innovative in environmental sustainability while internationalizing and exceling its competitive advantage through utilizing both foreign and domestic resources and digitalization. The paper also demonstrates how these companies share continuous knowledge across subsidiaries and other network systems with the support of their organizational forms and/or corporate governance structures. The study comprises Turkish manufacturing multinationals that operate in the continent of Europe. It examines 15 parent firms and 200 subsidiaries that conduct manufacturing operations in countries, such as United States, Germany, Spain, Italy, Netherlands, and United Kingdom. This empirical study employs system dynamics methodology by offering methodological propositions that will be useful for multinational companies.

Key Words: emerging market manufacturing business groups, environmental sustainability, innovation, digitalization, network systems.

INTRODUCTION

Over the last decade, the experience of fast economic growth, and the transformation to more liberalized market system in emerging market (EM) countries has motivated multinational corporations that originate in these markets to begin and/or to accelerate their investments and internationalization process in host countries in a large geographical scope. With this initiation, the global economy has been witnessing worldwide foreign direct investment (FDI) propelled, more and more, by Emerging Market Multinationals (EMMs), and Emerging Market Business Groups (EMBGs) that originate from EM countries.

These multinationals are becoming more integrated into the global market through their internationalization process, not only in developing countries, but in developed countries with advanced economies as well. Specifically, the investment efforts of EMMs into advanced economy countries have significantly increased (United Nations Conference On Trade and Development, 2015). Hence, EMMs from emerging markets, such as China, India, Mexico, and Turkey have been embarking diverse operations in developed countries.

Some of the prominent firms that have been undertaking operations in advanced economies are Turkish Business Groups (TBGs), namely Turkish Holding Companies (THCs). These Holding companies have been conducting manufacturing operations in numerous countries of Europe for many decades. In recent years, their operations took on innovation and environmental sustainability as the core principles in order to gain and to sustain competitive advantage. In doing so, they became efficacious in their international operations. However, it must be noted here that this efficacy is also related to their organizational forms and/or corporate governance structures.

Thus, the purpose of this research is to explore the internationalization processes of TBGs and the interplay between these processes and innovation, environmental sustainability, networks, and corporate governance dynamics. This study is descriptive as it focuses on the business dynamics of manufacturing Turkish Business Groups, namely Turkish Holding Companies. It gives a clear illustration of how manufacturing can be innovative and environmentally sustainable while internationalizing. The study is also normative as it provides propositions based on creating ownership advantage and competitive advantage through combining foreign and domestic resources and with the support of their organizational forms and/or corporate governance structures. It also reconnoiters the main reasons and key drivers for innovation, and environmental sustainability while internationalizing.

Deriving from the above research statement the research question can be stated as follows: 1a) What are the types of environmentally sustainable activities TBGs exploit while internationalization and digitalization? 1b) How do corporate governance structures affect these activities?

2) What are the innovative activities TBGs utilize while internationalizing? 3) What are the key drivers behind these innovative and sustainable activities, and how do corporate governance structures affect these activities?

This study employs a dataset of 15 manufacturing parent companies - holding firms, mostly made up of family-controlled business groups consisting of 200 of subsidiaries that conduct cross –border manufacturing in 17 countries mostly in the region of Europe. Data on business groups were obtained from “MarketLine Advantage”, “OneSource”, “DataStream”, and companies’ annual reports. The sample includes some firms listed as ADRs such as Haci Omer Sabanci Hodling A.S, Koc Holding, and Zorlu Holding, and those parent companies have at least one subsidiary firm (Arcelik A.S, Teknosa Ic ve Dis Ticaret, Vestel Beyaz Esya Sanayi ve Ticaret A.S etc.), quoted on the Borsa Istanbul (BI).

The rest of the paper is developed as follows: The following section provides some background information on TBGs and key drivers of their successful operations. The third section encapsulates previous literature; the fourth section illustrates the international innovative and environmentally sustainable activities of TBGs and summarizes findings; the fifth section develops propositions from the literature review and the findings; and the last section concludes and makes sense of the findings, and postulates contributions and limitations.

EVOLVING CONFIGURATIONS OF TGBs

For many decades the TBGs[1] have been the drivers of Turkish economy (Bugra, 1994; Öniş, 1992, 1995). They have been in the seen since the beginning of the foundation of the Republic of Turkey in 1923 from the ashes of a 600 year old Ottoman Empire. Turkish business groups can be identified as family-owned holding companies. They are mostly known as the essential form of large business institutions in the Republic of Turkey (Bugra, 1994; Bugra and Üsdiken, 1995; Öniş, 1995).

Their active undertakings, however, came with the industrialization process initiated by the Turkish government in the 1930s (Öniş, 1996). Yet, the real acceleration of their activities began with the stabilization program of 1980, which was instilled to correct major economic problems of the late 1970s through macroeconomic policies (Öniş, 1992).

Hence, began the liberalization and internationalization agenda. There were three goals for the stabilization program: 1) Reduction of government intervention in business and market activities; 2) Shifting from inward-looking, import-substituting industrialization processes to export-led growth; and 3) Attracting Foreign Direct Investment (FDI), (Öniş, 1992). This program actualized what it meant to do in a short time and led to high level of exports of manufactured goods. Acceleration of exports was also enhanced with the entrance of the Republic of Turkey into the Customs Union in 1996 (Sunar, 1996).

As it can be seen, most of the TBGs started as manufacturing firms with the encouragement of incumbent governments. Having had long experiences with manufacturing and exporting they developed innovative and sustainable capabilities over the years. Hitherto, their activities were

[1] A few examples of Turkish Business Groups and/or family-owned business groups include Koc Holding, Sabanci Holdin, Zorlu Holding AS,Calik Holding, Eczacibasi Holding, and Yazici Holding. These firms are among the largest firms by total assets in the Turkish Market (home-country market) and in the host country markets. Many family groups also have well-established historical presence in their home country market.

supported by the incumbent Turkish governments, but most importantly, by their corporate governance structures.

THEORITICAL DISCUSSION AND HYPOTHESES DEVELOPMENT

Since the main key drivers behind the innovative internationalization processes of TBGs were government initiatives and corporate governance, it may be crucial to integrate governance related research in the literature review.

a) Corporate Governance

Corporate governance is typically perceived by academic literature as dealing with 'problems that result from the separation of ownership and control'. From this perspective, corporate governance would focus on: The internal structure and rules of the board of directors; the creation of independent audit committees; rules for disclosure of information to shareholders and creditors; and, control of the management (Fernando, 2009, p. 9, OECD, 1997).

EMM literature that concentrates on governance suggests that EMMs have intensified their overseas operations. In addition, their role in the global economy has become more prominent during the last decade (Gubbi, Aulakh, Sougata, Sarkar, & Chittoor, 2010). The previous literature examines governance both at the home country and firm level. Firm level analysis illustrates the negative aspects of internationalization processes of these firms. It is indicated that while in advanced economies institutions and market dynamics work efficiently. Yet in emerging market countries, markets as well as institutions suffer from information asymmetry due to institutional voids (Khanna & Palepu, 1997). In this way, agency problems arise within the firms since managers desire to follow their own interests and to create costs to shareholders (Agrawal and Knoweber, 1996). Hence, understanding the emerging market multinationals require understanding the economic and institutional landscape in their home countries.

In emerging market economies there are various number of market and institutional failures. Some of these imperfections are presence of state governance mechanisms, insufficient transparency regulations, lack of intermediary institutions, and financial transparency (Khanna & Palepu, 1997; Leff, 1978; Yiu, Bruton, & Lu, 2005) Organizations, therefore, form conglomerates and business groups to diversify their risk and create balance in their portfolio (Yiu, Bruton, & Lu, 2005; Khanna & Palepu, 1997; Leff, 1978).

Corporate governance mechanisms as well as ownership structure, dividend payout, cost of external finance and market valuations have been significantly impacted due to variations in home country legal structure and the laws designed to protect investors, according to a growing body of literature valuations [(La Porta, Lopez-de-Silanes, and Vishny (1999); Klapper and Love, (2002)]. In some countries, firms may decline specific provisions causing investor protection laws to be nonbinding. ADR issuing firms may improve the rights of investors through implementing addition provisions to facilitate increased disclosure, institute more efficient and effective boards, and enact disciplinary action to ensure the rights of minority shareholders.

On the other hand, various studies (Klapper and Love, 2002) find a positive correlation between corporate governance structures and country level measures of investor protection. In addition, they suggest that it is crucial for firms located in countries with weak legal systems to adopt improved corporate governance practices. Since firms located in developing countries may have weaker rules, Black (2001) suggests that the corporate governance structures may have larger effects. Corporate governance is related to firms and firms from these emerging market countries set standards in the economies of these nations.

In the case of TBGs, government funding and corporate control of families draw minority investors to invest in these holding companies (Khanna and Yafeh, 2005). The previous studies also point out that t the internal capital markets created by business groups enable risk-sharing and intra-group financial support, in order to eliminate the problems caused by external capital constraints. In addition, these studies find that group affiliation in emerging markets is associated with better performance (Khanna and Palepu, 2000).

While the issues related to business groups and/or family-owned businesses remain a substance of academic debate, investors continue to invest in these businesses. This is especially the case in the case of TBGs, where investors put high value on their manufacturing operations, even though state controls the largest manufacturing firms (Bugra, 1994; Boratav, Türel and Yeldan, 1996; Öniş, 1996). Hence, the impact of family-group affiliation on TBGs' competitive advantage in innovation and sustainability may be a result of the benefits of concentrated ownership structure and variety of entrepreneurial skills and cultural ties in a family.

b) Digitalization and Innovation

In the case of TBGs creating competitive advantage through innovation and environmental sustainability greatly supports their internationalization processes. This is previously stated by previous literature among the studies of various EBGs. For example, numerous studies focus on the characteristic of business' environment pressure and its influence on firms' innovativeness. These studies show that different internalization phases or methods of a firm can be supported through digitalization and innovation (Cassiman & Golovko, 2011; Venaik, Midgley, & Devinney, 2005).

The innovative activities of TBGs are encouraged by the Turkish government; this has also been the case historically. They are able to enter into designated sectors through the support of network mechanisms and through instruments like protection from foreign competition, and Government-subsidized bank credits (Bugra, 1994).

In addition, the innovative activities of TGBs are also stimulated by diversification procedures. Diversification, mostly unrelated, has been enabled by 'technology acquisition' and 'project-execution' capability that they have developed in the process of digitalization over the years (Amsden and Hikino, 1994).

Hence, attaining capability is a crucial factor in a specific economy, as firms compete with each other as a result of conflicting demand and cost pressures in a host country (Venaik, Midgley, & Devinney, 2005). In order to overcome this conflict, firms can tap into international markets. As a result, they learn new capabilities specific to a firm (FSA) (Dunning, 1988) and leverage these abilities to innovate in home country or innovate across the globe (Gupta & Govindarajan, 1991). Addressing the reason/s of a firm's tendency to invest in certain markets rather than others is an important component to understand how business groups innovate.

As stated previously in the literature review related to corporate structure, in the process of innovating, firms may face corporate governance specific problems (Luo, Chung, & Sobczak, 2009). The business group affiliated firms are tied to each other in terms of ownership, control, experience, and knowledge flow (Khana & Palepu, 2000; Guillen, 2003). However, the bond among companies may positively (Guillen, 2003; Khana & Palepu, 2000) or negatively (Kim, Kim, & Hoskisson, 2010) affect firms' ability to adopt and react market changes. Not being able to embrace the changes can cause stagnation in innovation efforts. Therefore, investigating network relations and linkages between business groups and their innovative capabilities is crucial subject to understand business groups.

c) Digitalization and Innovation related to Networks and Linkages

Mahmood, Zhu & Zajac propose business groups have different abilities due to variety of member characteristics of business group associate firms (Mahmood, Zhu, & Zajac, 2011). According to the scholars, differently formed business groups have been engaged with different business activities. Therefore, they can sustain their activities in different industries and business fields (Mahmood, Zhu, & Zajac, 2011). However, the business groups' literature stem fail to provide what kind of business practices would create positivity. Henceforth, understanding and exploring linkage between different capabilities among business groups and how they may provide competitive innovation capabilities through digitalization for their members is crucial.

In Turkish business group structures, the parent companies have strong linkages and network relations with their subsidiaries and their main diversified firms. Network linkages can also be considered from a corporate governance perspective. Most corporate governance structures of Turkish business groups can be described as insider systems, much like the Japanese and the German systems where the firm, the bank and the state have a triangular relationship; hence the firm is financially supported by the state and the bank – within a network system, when necessary.

Networks in TBGs can also be related to family ownership, as these firms create numerous strategies to keep a strong family control in management. Most high-level positions and senior roles are usually reside by family members. The family members can also undertake a multiple managerial roles in the group (Bugra, 1994).

In relation to both network structures and innovation capabilities, it is important note that TBGs value 'professionalization of the family' through higher education of their young generations in business studies, and engineering, in prestigious universities abroad or at home (Bugra, 1994). Education received by the young members adds more innovation and value to the international operations of the business groups.

IV. Innovation, Environmental Sustainability, and Internationalization Perspective of Turkish Business Groups

It is important to point out here that in the past, most manufacturing EMMs actualized innovation through receiving technology from developed country multinationals and later adapting them to developing country standards, such as what the Indian multinationals did in some of the countries in the continent of Africa (Lal, White, 1985). However, TBGs, upon receiving technology from developed country multinationals, they promptly adapted them to other developed country markets; hence they sustain their ownership and competitive advantages in the manufacturing sector. They now create their innovation through their imaginative and artistic engineering processes and integrate the environmental sustainability and bring efficacy into their international operations.

In order to better observe their innovative operations, observation of the table below may be helpful. The table below illustrates that these firms are able to innovate as they internationalize.

Table 1: Parent Company Innovation and Subsidiary Information

Parent Company Name	Industry	Digitalization and Innovation	Environment Centric	U.N. Global Compact Members	Subsidiary Presence in West Europe
Koc Holding A.S	Petroleum Product Manufacturing	Innovative efficient production to create lasting value through sustainability perspective	"Koc holding and Group companies aim to turn risks into opportunities by solving environmental problems with creative and innovative solutions through the practices they pursue with a perspective that brings the priorities of sustainability to the forefront." Reforestation efforts and TEMA collaboration	Yes	France, Germany, Spain Italy, Belgium, Ireland, United Kingdom
Haci Omer Sabanci Holding	Holding/Banking	Achieving innovation-oriented growth via design and production of high technology goods with emphasize of sustainability.	Carbon Disclosure Project (CDJ). The holding aims to produce goods with minimal carbon footprint. The aim of CDJ is reducing greenhouse gas emission through regular investigation and proper investments	Yes	Germany, Belgium, United Kingdom, Spain
Zorlu Holding A.s	Holding Companies	Achieving strong market presence through creating and designing innovative	-	Yes	Spain, United Kingdom

		technologies			
Enka Insaat ve Sanayi A.S.	Civil Engineering	Re-examining current industrial practices with innovative engineering mindset to produce solutions and develop better and more efficient industrial techniques.	-	No	Germany, United Kingdom, Netherlands, Portgual.
Anadolu Efes Biracilik ve Malt Sanayi A.S.	Beverage Manufacturing	-	Green Packaging, efficient raw material usage, and reliable neighbor projects. These projects aim to reduce greenhouse gas emissions and contribute to efficient use of raw materials. Besides, Anadolu Eges supports the agricultural projects to attain sustainable raw materials from local farmers.	Yes	Netherlands, Germany
TAV Havalimanlari Holding A.S.	Air Transportation Services	-	TAV reveals its carbond disclosure data to asses, manage, and control the economic and environmental impacts of its activities. Since company highlights sustainability practices as an integral component of organization, it supports numerous environmental sustainability projects.	Yes	-
Adil Bey Holding A.S.	Holding Companies	-	The company actively engages with carbon emission reduction projects and reforestation efforts. One of the biggest projects of the company is known as “Eco-friendly Cars”. The company collaborates with the local government at this project to ban car traffic from touristic areas in Denizli. It targets to preserve wild	No	Netherlands, Germany

			life and cultural heritage of the city.		
Cukurova Holding A.S.	Holding Companies	Undertaking actions based on a viewpoint rooted in development and innovation.	United Nations Global Compact (UNGC) and “Agriculture Information Package” contributor. The holding supports eco-friendly agriculture and agriculture related education efforts. The purpose of these efforts is increasing environmental friendly practices in a sustainable production environement.	Yes	Spain
Yazicilar Holding A.S	Motor Vehicles and Passenger Car Bodies	The company motto is “developing reliable and environmental technologies to fulfill its social responsibilities.”	-	Yes	Germany
Sahinler Holding A.S	Clothing and Apparel Manufacturing	-	-	No	Germany
Tekfen Holding A.S	Residential and Commercail Building Construction	-	Junior Tema Project Sponsor. The company is a big investor to projects that focus on soil erosion prevention and reforestation. Also, the organization provides education to farmers to contribute eco-friendly and sustainable farming. The main focus on education that is provided is usage of fertilizers and agricultural chemicals	No	Germany
Celebi Holding A.S	Holding Companies	-	The company highlights its approach to environment via following quote: “Celebi’s goal is to be an organization whose practices make it the most environmentally sensitive company in the aviation industry through an approach that safe	No	Germany

			practices and enhances the quality of its employees and customers." The organization backs up this premise with investing in environment management system and supporting environment-focused projects.		
Calik Holding A.S	Holding Companies	The organization highlights its approach as "To add sustainable values to the lives we touched through our entrepreneurship, innovation, and reliability guided business operations."	-	No	-
Alarko Holding A.S	Architecture and Engineering	The organization adopt an approach which enables them to meet customer expectations with "innovative products in line with energy efficiency guidelines."	-	No	-
Eczacibasi Holding A.S	Pharmaceutical Manufacturing	The organization sees innovation as an vital component of their lives which affects its business success directly. According to the company, the most innovative thing is come up with a solution to "a consumer's real need".	Eczcibasi is known for its ecologic agricultural investments. One of the most well known examples is "Ormanda" project. The project aims to provide organic food to locals with environment friendly practices. In addition, the projects purposes to provide organic herbs to medicine industry and organic fertilizers to farmers.	Yes	Germany, United Kingdom, Italy

The "Table 1" provides insight about Turkish business groups' digitalization and innovative activities and how they disperse their subsidiaries in West Europe. As it can be interpret from the table, some of the business groups are well diverse than the others. The well diverse ones are mostly “UN Global Compact” members. Henceforth, it can be derived that the affiliation with an international institute assures well-organization structure and corporate practices that support innovation. It also can be argued that the actively engagement with corporate social responsibility projects provide further market opportunities.   It is also important to note here that these operations are actualized through network linkages and support of the corporate governance structure.

Table below “Table 2” illustrates the relationship between good corporate governance structures, diversification in manufacturing, and ownership and competitive advantage.

Table 2: Parent Company ADR Issue

Company Name	**Industry**	**ADR Listing Exchange (America)**	**ADR Ratio (America)**	**ADR Listing Exchange (Other Than America)**	**ADR Ratio (Other Than America)**
Koc Holding AS	Petroleum Product Manufacturing	Non-Nasdaq OTC (Non-sponsored) (@Kholy)	1:5	Stuttgart (D:KRKA) (STU)	1:5
Haci Omer Sabanci Holding A.S.	Banking	Non-Nasdaq OTC (sponsored) (@HOSZY), Non-Nasdaq OTC REG S ADR (@HOSXF), NYSE SPN. ADR.REG.S(26897H)	4:1, 4:1, (NA)	London (898044), Berlin (D:HAC1)	(NA), 1:250
Zorlu Holding AS	Holding Companies	Non-Nasdaq OTC UNSP. ADR (54588J)	NA	-	-
Enka Insaat ve Sanayi A.S.	Civil Engineering	-	-	-	-
Anadolu Efes Biracilik ve Malt Sanayi AS	Beverage Manufacturing	Non-Nasdaq OTC SPN. 144A (@AEBMY) , Non-Nasdaq OTC SPN. ADR. REG. S. (@AEBZY), Non-Nasdaq OTC V. ADR. 1 ADR = 200 SHS (25622N)	5:1, 5:1, NA	Stuttgart (D:EF41) (ADR REG S.), XETRA (D:EF4X), London (686260)	5:1,(NA), NA
TAV Havalimanlari Holding A.S.	Air Transportation Services	Non Nasdaq OTC UNSP. ADR (@TAVHY)	1:4	Stuttgart Uns. ADR (D:5THA)	1:04

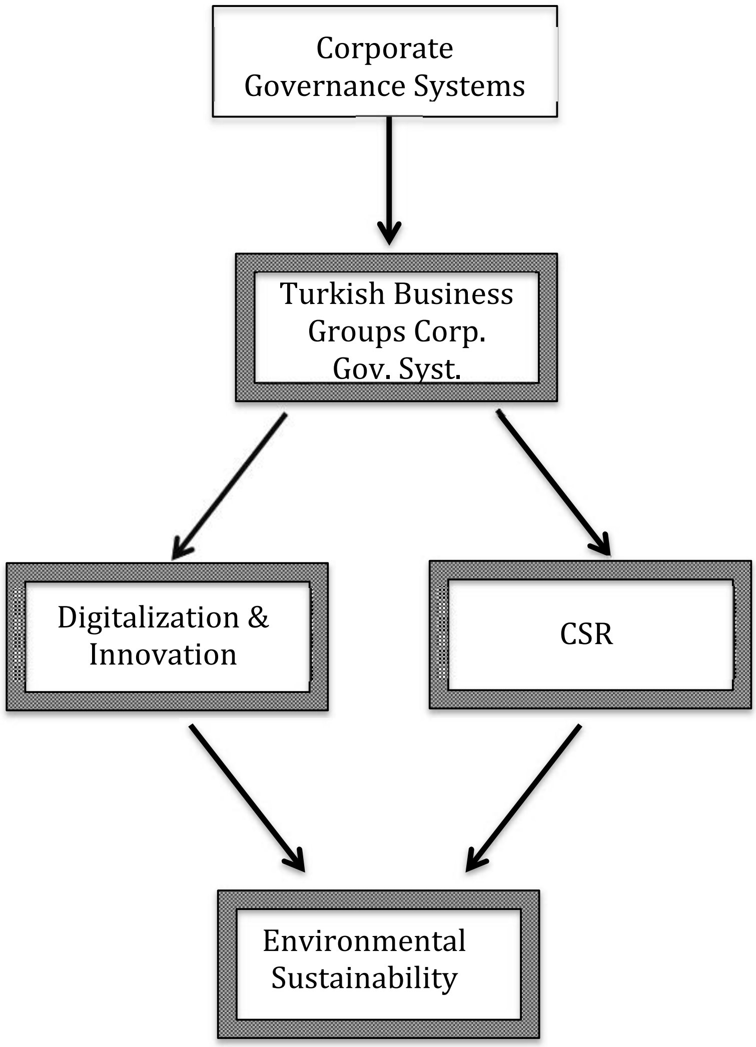
Adil Bey Holding A.S.	Holding Companies	-	-	-	-
Cukurova Holding A.S.	Holding Companies	-	-	-	-
Yazicilar Holding AS	Motor Vehicles and Passenger Car Bodies	-	-	-	-
Sahinler Holding A.S.	Clothing and Apparel Manufacturing	-	-	-	-
Tekfen Holding A.S.	Residential and Commercial Building Construction	Non-Nasdaq OTC UNSP. ADR. (@TKFHY)	1:4	-	-
Celebi Holding A.S.	Holding Companies	-	-	-	-
Calik Holding AS	Holding Companies	-	-	-	-
Alarko Holding A.S.	Architecture and Engineering	Non-Nasdaq OTC ADR 1:100 (879608)	-	-	-
Eczacibasi Holding A.S.	Pharmaceutical Manufacturing	-	-	-	-

It is apparent from the table that TBGs have good corporate governance structures. Good corporate governance structures, in return, encourage innovation and internationalization.

V. Methodological Propositions:

Based on the previous literature and the survey of TBGs' activities, this study offers the following propositions: 1) Activities related to digitalization, innovation and environmental sustainability of TBGs are supported by home-country governments; 2) Activities related to digitalization, innovation and environmental sustainability of TBGs are supported network linkages between parent company and subsidiaries; 3) Activities related to digitalization, innovation and environmental sustainability of TBGs are supported by diversification strategies; 4) Activities related to innovation and environmental sustainability of TBGs are supported by good corporate governance structures; and 5) Family-owned holding companies can have good corporate, which in turn encourages and cultivates digitalization, innovation and environmental sustainability as illustrated below:

Table 3: A Proposed Governance Structure Model



The table above clearly demonstrates the interplay and the support system encouraged by digitalization and innovation.

VI. Conclusion

This descriptive study focuses on the business dynamics of manufacturing Turkish Business Groups. It illustrates that manufacturing operations of TBGs can be innovative and environmentally sustainable while internationalizing. Normatively, the study provides propositions based on creating ownership advantage and competitive advantage with the support of their organizational forms and/or corporate governance structures. It also reconnoiters government support and network linkages as the main reasons and key drivers for digitalization, innovation, and environmental sustainability while internationalizing. Overall, our findings are consistent with previous research that Family-control business groups facilitate innovation and creativity.

The main contribution of this study to the International Business discipline is that the integration of digitalization, innovation, environmental sustainability and good corporate governance structures and networks to of emerging markets business groups. The limitation is that in this area there is difficulty in finding data and extensive previous research. The future research in this area needs to be empirical, so that an important contribution to the field can be actualized.

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Bridging the gap between theory and implementation for new business models for sustainability

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The scale and complexity of international business has increased exponentially. Firms are part of complex, international networks that pose various challenges in terms of difficult logistics and interdependent business processes across locations. In addition to these internal challenges, external pressure to consider the sustainability and resource use of supply chains is increasing: how does the economic performance of a firm compare to the environmental and social impact? How are the tensions between short-term profit and long-term sustainability needs mitigated? Business models for sustainability can be the guide companies need to answer such questions, and are recognized as a way to bridge the gap between the sustainable innovation necessary for sustainable development and the strategies employed by firms.

In order to implement sustainable business models, firms must undertake certain activities and perspectives to make their business model one that promotes sustainable innovation and that contributes to sustainable development in the larger system of which it is part. Although research on business models is generally extensive and literature on sustainable business models is growing, insight into the development and practical implementation of models that take into account the core issues of sustainability across life cycles, value chains and stakeholders is so far fragmented. Firms are faced with a multitude of social, economic and environmental aspects that must be considered within the company's value chain, and in relation to the environment and society surrounding them.

In addition to the fragmented research approach and potentially high upfront costs to implement a sustainable strategy, industrial actors have a difficult time translating normative sustainable business model theory into their practical business models. Even when firms aim to implement sustainability processes, it is often done so poorly – with high costs and uninformed decision-making resulting in small and short-lived changes – just to get the sustainability stamp for their customers, and diminishing the very goal of sustainability.

Elevating the status of environmental and social aspects into the core strategy of industrial firms requires a holistic approach to value creation and the redefinition of the term “innovation” to reflect societal values and environmental needs. To fill the gap between business model theory and the practical implementation of sustainable innovation, long-term knowledge must be developed in direct collaboration with companies and investors to contribute to a green shift in industry. Examples of such collaboration will be further demonstrated in the paper, providing insight into the practical transformation of manufacturing processes and supply chains.

Partner Selection, Legitimacy and the Growth: A Case Study of the Social Enterprise

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Abstract: Different from profit organizations and non-profit organizations, the effectiveness of social enterprises governance is the key factor of its growth in the case of conflictive institutional logics. However, there is no overall and objective framework of governance to be used for analyzing the actual situation of social enterprise governance. The purpose of this paper is to present the findings from a social enterprise case study, and focuses on three questions:(a) how the social enterprise do the field governance and partner selection? (b) how the social enterprise gain legitimacy through field governance and partner selection? (c) how the governance influence the growth of social enterprise? Our results show that when lacking legitimacy in a given field, the social enterprise may try to do the partner selection and field governance to gain acceptance. Overall, our findings contribute to a better understanding of how organizations can survive and thrive when embedded in pluralistic institutional environments. This study will give a theoretical basis for promoting the growth of social enterprises.

Keywords: Field Governance; Partner Selection; Legitimacy; Social Enterprise

Over the last 30 years, we have witnessed an unprecedented increase in the number of organizations that operate at the intersection of the social and commercial sectors, which are often called “social enterprises” (Battilana&Dorado, 2010; Galaskiewicz & Barringer, 2012; Hoffman, Gullo, & Haigh, 2012; Pache& Santos, 2013). They straddle the well-established categories of business and charity (Austin,Wei-Skillern& Stevenson, 2006; Mair & Marti, 2006), and are thus “hybrid” organizations, combining aspects of multiple organizational forms(Battilana & Lee, 2014; Haveman & Rao, 2006). In recent years, social enterprises have sprung up throughout China. This growing pervasiveness of hybrids can be explained by the increasing prevalence of pluralistic institutional environments (Greenwood,Raynard, Kodeih, Micelotta, & Lounsbury, 2011;Pache & Santos, 2010; Seo & Creed, 2002). In these complex environments, organizations are exposed over lengthy periods of time

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to multiple institutional logics. Because of this, the biggest challenge they may face is that they are failed to satisfy various kinds of interest (Battilana & Lee,2014). In other words, many social enterprises in China are hard to be approved by their stakeholders in the external environment including the government, enterprises, non-profit organizations and so on, and all these lead them hard to survive.

But at the same time, why do some social enterprises survived, and indeed thrive, but some are closed down in the same condition? This puzzle suggests that how social enterprises carry out the field governance have not yet been systematically uncovered by organizational researchers. In particular, we know very little about how social enterprises seek to manage the different relationships among all kinds of stakeholders, and the possible outcomes for these organizations. Thus in the perspective of social network, we regard the social enterprise as an actor, and it tries to construct and govern its external field to survive. Specifically, our study seeks to answer the following research questions: How the social enterprise selects its partners to survive? And how it manages the relationships with different kinds of partners?

To answer these questions, we conducted an in-depth case study of XZ, a social enterprise located in Hangzhou, Zhejiang Province in the East of China. This area has experienced a time that it is hard to find a job over the past decade. XZ was one of the few organizations in the area which has set up a dedicated program to support the fresh college graduates by offering them cheap accommodation and help them to find a job in Hangzhou.

THEORETICAL BACKGROUND

What has been known about the way social enterprises do the field governance? To deepen our understanding of its strategies for survival, we reviewed research on organizational field (Powell & DiMaggio,1991), and partner selection (Baum,2010). We review these researches in details as below.

Organizational Fields

Organizational field refers to those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that provide similar services or products (DiMaggio&Powell,1983), or can be regarded as a organizational community; compared with the external actors, the organizations in the community are more closed(Scott,2010).The concept of organizational field is derived from Bourdieu's illustration of the conception of field. In Bourdieu's view, field is a kind of practice space which is the mediator between macro social environment and micro actors. Moreover, external factors such as economy, politics, culture will be reshaped by the field, and they will influence the actors in the field indirectly (Bourdieu, Kant, 2004). The formation of the organizational field is a process in which the organizations try to construct the system of rules, the boundary of field, the standard of members' behaviors through consultations and negotiations, cooperation and competition (DiMaggio & Powell, 1983).

The concept of organizational field is concerned about the relational structure and logic model among the organizational community, which is derived from social constructionism, which means the social phenomenon occurs in a particular social situation, and knowledge, including even the widely accepted knowledge, are derived from social interactions. The formation of organizational field depends on the interactions between individuals and groups, which leads to the creation and institutionalization of social reality (Berger&Luckmann, 1967).So the organizations in the same field always have the specific goals and interests, and all of them are affected by the broader institution system, at the same time, they interact through the field, and reshape the institutional environment (Scott, 1999).

Some institutional researchers have claimed that legitimacy constraints the behaviors of individuals and organizations (Meyer&Rowan, 1977). According to the institutional theory, once an actor enters into a certain field, it will be restrained by the power of regulatory isomorphism force, the imitate isomorphism force and the normative isomorphism force (DiMaggio & Powell, 1983). And the actor has to take some actions to obtain legitimacy. There are three kinds of legitimacy: pragmatic legitimacy, moral legitimacy and cognitive legitimacy(Suchman, 1995). But not all organizations will face the same degree of legitimacy pressure, when they are compliant to it, some may take actions to deal with (Suchman, 1995). In recent years, more and more researches turned to focus on the process of institutionalization, and begin to pay close attention to the individuals or organizations on how to manage the institutional environment, and try to explore how actors facilitate new organizational forms, or new practices (Greenwood & Suddaby, 2006).

Partner selection

Rapid development of inter-organization networks makes relationship of partner selection a core issue in inter-organization relationship research. Rational partner selection is conductive to formation of stable and effective strategic partner relationships and the advancement of inter-organization value co-creation. Nowadays, the research about partner selection is mainly focused in four aspects, namely knowledge matching (Shan&Swaminathan,2008), relationship interaction (Hitt,2000;Gulati,1995), strategic synergy (Das,2006;Gallagher,2007;Roy &Oliver,2009), institutional embeddedness (Roy,2012;Hitt,2000).

We focus on the last aspect——the institutional embeddedness. Partner selection is one of the important strategic decisions of the organizations, which will be influenced by the institutional environment, such as political, economic, cultural and legal factors. In other words, the partner selection decisions are embedded in the specific institutional environment, and how to choose partner depends on the specific context. Based on this theory, some scholarstry to explore the partner selection decisions of organizations (Hitt, 2000; Li and Ferreira, 2008; Roy, 2012).

METHODS

To explore these research questions, we have developed an inductive case study of a social enterprise in China. The case study is a method used to answer the problem of "why" and "how" (Yin, 1994). The purpose of this article is to study the effects of partner selection and field governance made by social enterprises, and it is a question about “how”; On the other hand, studies of how social enterprises carry out partner selection and field governance is still a “black box”, remaining to be studied for this case study method is a suitable way for this paper (Eisenhardt, 1989). In the next section, we briefly present the field of the social enterprise and its history, moreover, we will also explain the process of data collecting and analyzing.

Research Sampling

For the research content, we select a case according to the following standards: first, the availability and sustainability of data. The case we selected must have been set up for a period of time in order to obtain a more comprehensive and long-term data which will enable research to go smoothly. Second, the case must be typical in the social enterprises domain. And in the two standards, data availability is the key to be considered in this paper.

According to standards we mentioned above, we chose a social enterprise named XZ as a research object. XZ is a hotel just for college students, which is located in Hangzhou, Zhejiang Province. It is the only one registered hotel for college students.

In XZ, there are more than 200 beds, 24 hours hot and cold water shower, and each room is equipped with TV, air conditioning and other electrical appliances. The price is about twenty to thirty Yuan a day. Meanwhile, XZ is not only a hotel, but also a place providing personnel services such as help college students look for work, They have a matchmaker team which can provide job training for personnel and recommended enterprise interview.

Data Collection

This paper follows the method proposed by Miles and Huberman (1994) which is described as the triangular validation method (Triangulation) to avoid research bias. So we take different ways to collect research materials including interviews, archive materials and some media reports. First, we conduct in-depth interviews with the founder of XZ. For nearly two years in 2015 and 2016, we have conducted the semi-structured interviews with the founder for three times, and each interview lasted about two or three hours. Second, we have collected some media reports about XZ, including news reports (authority and the mainstream media), publications (internal periodicals, relevant rules and regulations, etc.) and its official website, etc. In case some of the data information in public is not correct, it will be sent to XZ for conformance and the correct information. Third, we looked up the archive materials to find out how XZ developed during the past 8 years.

Data Analysis

Our approach to data analysis followed common prescriptions for inductive qualitative data analysis (Corley & Gioia, 2004; Zietsma & Lawrence, 2010). In the first step, we collected the various information from the interviews, internal documents, and newspaper reports in order to produce a “database”. Meanwhile, we sought to ensure that the narrative was as balanced as possible, and incorporated the different perspectives that were apparent in our data.

In the second step, we conducted an initial coding process. We examined each source of data (the interview transcripts, internal documents, and newspaper coverage) to look for similarities and differences between them. Moreover, we tried to conceptualize some information.

In the third step, we focused on the core words “partner selection” and “relationship”, and then shifted our focus to how they affected the growth of the social enterprise, and classified the conception we made above into “partner selection”, “relationship” and “field governance”. The process was iterative rather than linear, and involved moving among the data, the relevant literature, and the emerging patterns in order to refine the data into particular conceptual categories (Eisenhardt, 1989).

In the fourth step, we tried to propose some meaningful hypothetical propositions.

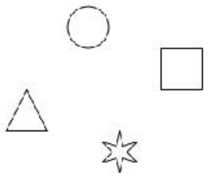
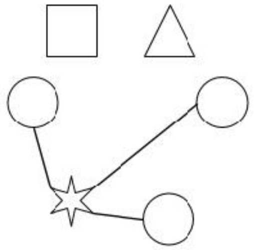
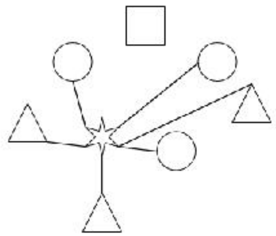
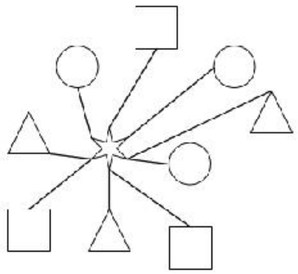
Table 1 The Key Events of XZ

Time	Events
2008.7	XZ was set up
2008.12	10000 free beds for job-hunting students
2009.2	Gain support from the Mayor of Hangzhou municipality
2009.10	Be named as “Training Bases For College Students”by the Communist Youth League of Hangzhou
2010.3	Held the discuss meeting for the colleges and companies in Hangzhou
2010.8	Be named as “Training Bases For College Students for Entrepreneurship”by the Communist Youth League of Hangzhou
2010.10	Cooperate with Jiangxi Provincial Department of Education to hold recruitment activities
2015.6	Cooperate with Alibaba to foster talented person on Cross-border of E-Business
2015.8-now	Plan to establish an alliance of social enterprises with some social entrepreneurs

FINDINGS

Pache and Santos (2010) proposed that the structure of the organization in the field has two key dimensions, namely fragmentation and centralized. Fragmentation is refers to the number of members in the field, and this members rely on each other in order to gain legitimacy and resources, but they are not get well along with each other.In a highly fragmented field, organizations have to respond to the multiple demands which have different kind of institutional logics with each other,and sometimes they may be conflict. Centralization refers to that there is a active agent in the field.

Table 2 The Field Evolution of XZ

		Stage 1	Stage 2	Stage 3	Stage 4
Partner selection		XZ was set up	Cooperate with the government	Cooperate with some companies	Cooperate with some social enterprises
Active or passive		None	passive	Active	Active
Structure of Field					
Characteristic of Field	fragmentation	High	Low	Moderate	Low
	centralization	Low	Low	Moderate	High

○ Refers to the department of government □ Refers to other social enterprise △ Refers to the companies

Partner Selection

Stage 1 XZ was set up

In stage one, we can see that actors in the field take their own measures and the legitimacy of social enterprises is at low level. At present, the fragmentation of the current field is at high level, which indicates the organization depends on and needs to respond to multiple and unharmonious subjects. These subjects have their respective logics as to what is effective or legal behavior, which leads to conflicts possibly existing inn system requirements. In the meantime, the centralization degree is relatively low in the stage which indicates that there is no a dominant central logic and actor. In the stage, XZ is in rebirth period which has not started its governance as to internal partnership relationship within field. In the meantime, in the stage, other organizations in the field like government department, enterprise, and non-profit organizations have superficial understanding about social enterprises without action taken which are still in the stage of waiting and observing.

Stage 2 Passive governance

In stage two, we can see through combining table 1 and table 2 that XZ takes some measures to gain certain legitimacy. In the stage local government department has further understanding about social enterprises. However, at national level, there is no acknowledgment about social enterprises. As pioneer of social enterprises, XZ has further understood the importance to gain government's support even government departments to achieve cooperation. In the stage, XA is in passive cooperation with the government departments rather than active selection of partners, thus making field governance. Through cooperation with government departments such as establishing university student internship base of municipal corporation, XZ has successfully established certain legitimacy within social scope. The fragmentation is relatively low in the stage, for that XZ only need to satisfy the requirements of government department. And the centralization degree is relatively low for that there has no dominant actor formed in social enterprise field.

Stage 3 Active governance

In stage three, we find that XZ starts to choose partners actively thus making field governance. Through cooperating with Education Department in Jiangxi, XZ develops towards the national market. In the meantime, it makes strategic cooperation agreement with Alibaba and opens new chapter of cooperation between social enterprises and business enterprises. Through cooperation with government departments and large scaled enterprises, XZ provides for university students with cheap beds and helps university students in job hunting which have won social acknowledgement gradually, whose legitimacy of existence has been improved constantly. In the stage, the degree of fragmentation of the field is appropriate. XZ needs to satisfy two kinds of different system logics of government departments and business enterprises. The centralization degree of field is gradually improved. The dominant status of XZ is gradually manifested.

Stage 4 Cooperate with some social enterprises

In stage four, we can see that XZ is still making field governance and starts to be committed in joint with other social enterprises to establish social enterprise alliance in order to gain resources for organization development. In this stage, the fragmentization degree of field is high and XZ has been in dominant status.

DISCUSSION: UNDERSTANDING SOCIAL ENTERPRISES

Our study seeks a better understanding of the social enterprise, which is defined as organizations that incorporate competing institutional logics(Battilana & Dorado, 2010; Greenwood et al., 2011; Haveman & Rao, 2006). A thorough examination of organizations in the field of social enterprises in China allowed us to discover how hybrids that are persistently embedded in competing institutional logics combined elements of the competing social welfare and commercial logics gain legitimacy through partner selection. Below we elaborate on each of these findings and discuss our contributions.

Findings

Our results show that when lacking legitimacy in a given field, the social enterprise may try to do the partner selection and field governance to gain legitimacy and acceptance. We can see, at the Stage 2 and Stage 3, XZ tried to get along well with the government and some big firms to gain acceptance. And in the Stage 4, when XZ have gained the cognitive legitimacy, it tried to do the field governance more actively.

Contributions

In developing our arguments, our study makes two contributions. The first contribution is that we think the social enterprise and its stakeholders has consisted a network, which can be named field, which has enriched the research of social enterprise. Second based on post-structure paradigm, we try to analysis the actions taken by the social enterprise to gain legitimacy, and answered the question that why some social enterprises survived but some closed down.

Limitations and Future Research

An important issue in case study research is the degree to which findings are generalizable to a broader population. Our work certainly contributes to a growing stream of practitioner literature on social enterprise, more narrowly defined as organizations oriented toward both the market and the social goals (Boyd, Henning, Wang, & Welch, 2010; Hoffman, Gullo, & Haigh, 2012). However, we just do the research to one classic social enterprise in Hangzhou. In generalizing these results, it may be important to take into account the different places and kinds of social enterprises. Also, it would also require exploring the role played by organizational leaders in this process, to understand what explains their capacity to do partner selection and field governance.

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Internationalization through business model innovation: A perspective of legitimacy

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Abstract: Firms that operate in multiple countries have to choose between exporting their existing business model to a new market, adapting their existing business model, or developing a new model for every new market (Cavalcante, Kesting & Ulhoi, 2011; Dasilva & Trkman, 2014). The repeated application of a specific business model has been found to contribute to firms' rapid and early internationalization (Dunford, et al., 2010). It is though a challenge for firms to implement their original business model in new markets, especially in emerging markets with different institutional and cultural contexts as well as institutional voids (Khanna, Palepu, & Sinha, 2005; Prahalad & Mashelkar, 2010; Fleury & Fleury, 2014). Business model innovation is a viable tool for firms to realize internationalization and expand to multiple countries. However, it is still unclear that how firms could achieve business model innovation through evolving with the host country environment. The mechanisms of how business model innovation could help firms get legitimacy in the host country, and in turn sustain the successfulness of internationalization remains a black box.

The purpose of this paper is to understand how firms achieve internationalization through business model innovation. This research is a qualitative study based on comparative cases on three foreign academic ebook platform firms in Chinese academic ebook industry, which industry is greatly affected by the constraints of severe intellectual property environment, government censorship policy as well as the opportunities such as expanding markets and unsatisfied customers' need. Different types of business model innovation are identified from the perspective of legitimacy.

We seek three contributions in this research: Firstly, this research bridges internationalization and business model studies, and opens a new venue for further studies on business model innovation. Secondly, this research extends understanding of the role played by business model innovation in internationalization especially in emerging markets. Thirdly, this research comes to an integrative framework of how firms' original business model limited by institutional voids, and how firms could gain legitimacy through business model innovation (institutional voids →business model innovation → legitimacy), which theoretically interprets the phenomenon of various internationalization paths for ebook platform firms to operates in Chinese ebook market.

Key words: Business model innovation, Legitimacy, Institutional Theory, ebook industry.

To License or Sell: A Study on the Patent Transaction Modes in China

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Abstract:

Analyzing a unique database, this study investigates the determinants of transaction modes of invention and utility model patents in China. The results suggest that there is an inverted U-shaped relationship between an invention patent's quality and the probability of it being licensed out while no relationship exists between a utility model's quality and the probability of it being transacted. We also find that a firm with economically-motivated patent strategies is less likely to sell its invention patents while a firm with administratively-motivated patent strategies is more likely to transact its patents.

Keywords: Patent; Licensing; Sale; Transaction Mode; Technology Transfer

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1. Introduction

Licensing and selling patent represent two important forms of technology transfer. The central research question of this study is what are the main factors that affect corporate patent transaction mode decisions (i.e., licensing, sale or internal use) for commercialization in technology marketplace. Scholars have long realized that licensing or sale of patent is not only for obtaining monetary revenue but also for executing corporate strategies (Lichtenthaler, 2011). Kollmer and Dowling (2004), Lichtenthaler (2007), and Bianchi et al. (2014) have argued that unique position in market, different capabilities as well as distinctive resources of a firm influence its choice on licensing, sale or internal exploitation of the patents through new product development. Previous studies have examined patent-, firm- and market-level factors that affect the probability of a patent to be licensed or sold. Factors at the patent-level include technology generality (Gambardella, 1998; Gambardella et al., 2007), economic value or quality of patent (Gambardella et al., 2007), strength of patent protection (Gallini, 2002; Arora and Ceccagnoli, 2006). The firm-level factors include firm size (Gans and Stern, 2003), competition strategy (Gambardella et al., 2007), IP management capabilities (Srivastava and Wang, 2014), corporate transaction experience, transaction partner relationship (Kim and Vonortas, 2006). The market-level factors are enforcement of patent right, difficulty in reaching licensing deal and intensity of competition (Kani and Motohashi, 2012).

While the previous studies have examined the choices of licensing versus internal use of patent or sales versus internal use separately (Wang et al., 2014; Wang et al., 2015a, 2015b), there are few studies of examining the transaction modes, i.e. licensing, sale, internal use altogether. The study by Jeong et al. (2013) is an exception, as the authors found firms licensed patents when uncertainty is low or transaction cost is high, whereas firms sold patent under opposite conditions. We contribute to this line of research by taking into account patent commercialization (technology transfer) decisions as a spectrum of modalities rather than segmenting patent licensing and sale from each other as featured in most of the abovementioned literature.

In addition, in many of the previous studies, the scholars were not able to distinguish the two different reasons why a patent is not licensed or sold, that is, the value of a patent is too low to be licensed or sold or the value of the patent is so high that the owner keeps it for internal use. We are able to overcome the difficulty in this study by using R&D cost of patents reported by the company participating in the Chinese Inventor Survey as a proxy of patent quality.

A unique feature of the Chinese patent system and its recent development is the patent subsidy given by various levels of governments, which contributes to the patenting surge in China in the last decade (Li, 2012; Dang and Motohashi, 2015; Boeing and Mueller, 2015). Scholars found that one of the direct effects of government subsidy is generating low-quality patents. However, we know little about the impact of subsidy policy on the technology market and the patent transaction activities. Analyzing patent applicants' motivation of applying for and maintaining patents which is documented in the Chinese Inventory Survey, we are able to quantitatively measure the impact of government subsidy on the transaction of patent.

The novelty of this study also lies in that we analyze a novel Chinese Inventor Survey Database, constructed by the State Intellectual Property Office of China, which provides rich information on corporations as patent applicants and the patents they own and matches it with a commercial patent database incoPat, where the full history of the licensing and sale of patents is available. Matching these two databases, we are able to investigate the factors such as patent quality, corporate patent strategy and corporate IP management in the Chinese context which are rarely examined in the previous studies. We find that there exists an inverted U-shaped relationship between an invention patent's quality and the probability of it being licensed out while only a positive relationship exists between its quality and the probability of it being sold. We also find that a firm with economically-motivated patent strategies, such as such as cross-licensing, blocking competitors or protection of early-stage R&D, is less likely to sell its invention patents while a firm with administratively-motivated patent strategies, such as obtaining government subsidy and certification, are more likely to transact its patents.

The rest parts of this paper are organized as follows: the second section develops hypotheses based on strategy and organization theory; the third section describes the data, method and variables of the empirical study; the fourth presents regression results for inventions and utility models respectively; the final section discusses the results and concludes.

2. Theory and Hypothesis

2.1 Patent quality

We identify patent quality as a primary factor that patent owners consider when making decisions of keeping, licensing, selling, or adopting a combination of tactics to maximize short-term economic returns and long-term returns (achieving technological leadership in the market). Patent owners often face high search and transaction cost when engaging in patent licensing and sale activities, especially in an immature technology market (Srivastava and Wang, 2014). They find difficulty in locating potential buyers, acquiring information about potential negotiators and may be harmed by potential buyers' opportunism during the negotiations (Agrawal et al., 2014). The transaction cost theory suggests that if transaction cost is too high, a firm will choose to exploit a patent internally. Thus the likelihood of licensing or selling a patent may increase with quality of patent (Shane, 1994; Kim and Vonortas, 2006; Jeong et al., 2013).

The resource-based view theory, however, suggests that the willingness of companies to trade patents may decrease with patent quality because firms prefer keeping valuable patents for internal use. On the one hand, a patent must satisfy statutory criteria, i.e., novelty, non-obviousness or industrial applicability, to be granted (Zuniga et al., 2009). Therefore, every patent is unique to some extent and is of certain value (current value and potential value). Moreover, the value of patent is context dependent. As the technological or market condition of a firm changes, the value of the patent it possess may also alter (Sherry and Teece, 2004). Improper transfer may cost patent owner an opportunity of extracting future value. On the other hand, the tacit knowledge associated with a patent, which is not revealed in the patent document or may even be hidden intentionally by patent applicants, makes the patent inimitable and difficult to be utilized efficiently without the inventors' help. Therefore, patents, especially those of high quality, are hardly substitutable and become sources of sustained competitive advantages of a company (Barney, 1991; Rumelt, 1997). Given that licensing or sale of high-quality patents may result in knowledge leakage and provide current or potential competitors an opportunity to acquire important technology assets, companies are less likely to transact, especially sell their own high-quality patents (Grimpe and Hussinger, 2014).

Due to the above two opposite effects of patent quality on patent transaction, it is logical to suspect that there may exist curvilinear (inverted U-shaped) relationship between patent quality and transaction (Haans et al., 2015). In other words, at a low level of patent quality, the probability of transaction may increase with patent quality. However, at a high level, the probability decreases with patent quality. We develop the following three hypotheses to investigate the relationship between patent quality and patent transaction modes.

H1a: There is a positive relationship between the probability of patent transaction and patent quality.
H1b: There is a negative relationship between the probability of patent transaction and patent quality.
H1c: There is an inverted U-shaped relationship between the probability of patent transaction and patent quality.

2.2 Corporate patent strategy

As a part of corporate strategy, patent strategy refers to strategic arrangement to gain competitiveness through acquisition and effective management of patents (Somaya, 2012). Sasak et al. (2001) argued that corporate patent strategy includes three sub-strategies, namely patent application, exploitation and organization strategy. Somaya (2002) classified corporate patent strategy into aggressive and defensive ones. The aggressive patent strategies in his view include strategic enclosure (Lerner, 1995; Lanjouw and Schankerman, 2001), harvesting licensing revenue (Arora and Fosfuri, 2013) and patent troll (Bessen and Meurer, 2008). The defensive patent strategies consist of strategic isolation (Lerner, 1995), strategic defense (Somaya, 2002) and multi-invention organization choice (Somaya and Teece, 2001) and combined strategies such as patent portfolio (Ernst, 2001). Apparently, a company can develop multiple patent strategies simultaneously and execute them accordingly with regard to different products, technologies and markets. The corporate patent strategy thus determines corporate behavior concerning patenting activities and choice of patent transaction modes (Caviggioli and Ughetto, 2013).

Applying for patents to negotiate cross-licensing deals and mitigate royalty payment is a common corporate patent strategy, especially for the companies operating in a complex technology industry such as the electronics industry (Köhler, 2011). To gain bargaining power in cross-licensing negotiations, patents are considered as strategic assets and less likely to be sold to the other parties than to be kept for internal use (Edvinsson and Sullivan, 1996). Similarly, if a firm develops strategies to use patents to prevent others imitating its technology, enhance corporate image, set product standard, block competitors or protect the early-stage R&D, the patents have lower probabilities of being transacted as well. We call these strategies based on the intrinsic principle of market-oriented economy instead of on responding to governments' incentive or administrative requirements as the economically-motivated patent strategies.

As a part of institutional environment, governmental policy has influence on corporate decisions related to transactions (North, 1990; Williamson, 1991). Research also shows that institution affects enterprise's behavior including IP transactions (Gans et al, 2008; Kostova and Dacin, 2008). In China, the past decade has witnessed a remarkable growth of patenting activities and the policy has played an important role in this patenting surge (Li, 2012). It is estimated that about 30 percent increase of number of patents application has been driven by government policy (Dang and Motohashi, 2015). If a firm' patenting activities are incentivized by government subsidy on patent application fee, or to meet criterion of high-technology company to enjoy tax reduction[2], or to fulfill the administrative requirements set up by government agencies, the firm would be rational to transact the patents after the objective is fulfilled. Otherwise, it has to bear the cost of maintaining the patents. We dub this type of corporate patent strategies as administratively-motivated patent strategies, which are not determined by market force, but rather influenced by government intervention. In line with the above reasoning, we develop the following two hypotheses.

Hypothesis 2a: A firm with economically-motivated patent strategies such as cross-licensing, imitation prevention, enhancing corporate image, setting standard, blocking competitors or protection of early-stage R&D are less likely to transact its patents than keep the patents for internal use.
Hypothesis 2b: A firm with administratively-motivated patent strategies such as obtaining government subsidy and certification are more likely to transact its patents than keep the patents for internal use.

2.3 Corporate IP management

Scholars argued that "Learning by transacting" is an effective way for companies to accumulate knowledge and experience in IP management. (George, 2005; Clarysse et al., 2009; Srivastava and Wang, 2014). Firms with lower IP management capabilities can take part in transactions to improve existing competence. However, the likelihood of completing transactions would be lower for them than for the firms with higher IP management capabilities. A company with specialized IP department is considered to have superior capabilities than a company which manages its IP activities through a part-time organization

[2] 5XUS 9GT[GX_ (YZ$)''/$ ZNK IUSVGT0KY 0T 3N0TG]N0IN GXK IKXZ0L0KJ GY N0MN%ZKINTURUM_ IUSVGT0KY IGT KTPU_ G XKJ[IKJ ZG^ XGZK UL (, 0T IUSVGX0YUT ZU ZNK XKM[RGX ZG^ XGZK UL), &CU VGYY ZNK IKXZ0L0IGZ0UT$ G N0MN%ZKINTURUM_ IUSVGT_ NGY ZU VXKYKTZ K\0JKTIK ZNGZ 0Z U]TY 0TZKRRKIZ[GR VXUVKXZ_$]N0IN 0TIR[JKY VGZKTZY !<0T0YZX_ UL BI0KTIK GTJ CKINTURUM_$ <0T0YZX_ UL 50TGTIK GTJ BZGZK 1JS0T0YZXGZ0UT UL CG^GZ0UT$)''/"&

or no organization at all, because a specialized IP department would have its own budget, staff and work process and can be engaged in more patent transaction activities than otherwise do. However, a competing hypothesis would be that if the patenting activities and strategies of a company are managed by a specialized organization, the company would have better structure and capability to create patents as strategic assets, have higher probability of retaining the assets and exploiting their value internally. Then we would observe that the company's patents are less likely to being transacted. Therefore, we develop the following two hypotheses.

H3a: The probability of patent transaction is higher for the patents managed by a specialized IP department than those managed by a part-time IP department or no IP department at all.
H3b: The probability of patent transaction is lower for the patents managed by a specialized IP department than those managed by a part-time IP department or no IP department at all.

3 Data, Methodology and Variables

3.1 Data

To test the above hypotheses, we construct a novel database by merging data from two patent databases: The State Intellectual Property Office's (SIPO) Inventor Survey Database and the incoPat Patent Database (incoPat).
The inventor survey has been conducted annually by the SIPO and provincial Intellectual Property Bureaus since 2008. It uses a Probability Proportionate to Size sampling technique, and contains vast and highly-reliable information on sampled patents. The sampling framework of each year's survey includes the patents granted in last year. In this study we analyze the data of the 2012 survey, which accordingly represent the patents granted in 2011. In the 2012 survey, 44,850 questionnaires were sent out and 38,837 were returned with a response rate of 86.7%. Among the returned questionnaires, 26,204 were answered by 9,568 companies, 10,673 by 994 universities or research institutes and 1,702 by 1,508 individual inventors. We focus on patents owned by companies in this study, and draw on the rich firm- and patent-level information related to the invention from the questionnaires (that is, the cost of invention protected by the patents in question, patent strategies and IP management of companies, firm size, ownership, technology field of the patents, and so on).

IncoPat is a commercial patent database, containing global patent information drawn from 102 countries and territories all available in Chinese. Its database collection contains more than 105 million patents from around the world, and is updated on a weekly basis. IncoPat contains the Chinese invention, utility, and design patents applied for from September 1985 when the modern Chinese patent system was established until today. The information which can be retrieved and downloaded contain patent title, abstract, application date, grant date, legal status, citations, patent family information, licensing and sale history and so on.

According to the Chinese Patent Law, a contract of patent sale can only be effective upon registration of the contract in the SIPO. According to the SIPO Regulation on Registration of

Patent Licensing Contract (SIPO Regulation No. 62 and 18), the parties signing a patent licensing contract should register the contract in the SIPO within three months after the contract becomes effective. The parties involved in patent licensing and sale deals therefor have legal obligation to register their transactions in the SIPO. The registration information obtained by the SIPO and collected by the incoPat becomes the basis for this empirical study.

By matching the patents' unique application number, we are able to merge both the 2012 data of the inventory survey and the whole incoPat Patent Database, and have access to a comprehensive array of information of 19,518 patents, including 11,320 invention and 8,198 utility model patents granted in 2011. We exclude design patents because they do not represent technological innovation and are not directly comparable to invention and utility model patents. 1SUTM ZNK OT\KTZOUT VGZKTZY$ O$.,O !/- UL (($*)'" NG\K _KZ HKKT ZXGTYGIZKJ H_ >IZUHKX)'(,]NKT ZNOY VGVKX]GY]XOZZKT$ H[Z *). !* " NG\K HKKT ROIKTYKJ GTJ ($)*+ !((" NG\K HKKT YURJ& 1SUTM ZNK [ZOROZ_ SUJKR VGZKTZY$.$--, !O* UL /$(O/" NG\K _KZ HKKT ZXGTYGIZKJ$ (*(!) " NG\K HKKT ROIKTYKJ GTJ +') !, " NG\K HKKT YURJ&

3.2 Regression model

We assume that firm managers' choices over transaction modes are based on their assessment of patent quality and corporate patent strategies and are constrained by the IP management structure of the companies and so forth. The appropriate model to investigate the relationship between transaction modes and above factors is a multinomial logit, shown in equation 1, where the bold characters represent vector or matrix.

(1) $\text{Prob}(\boldsymbol{Y_i} = j|\boldsymbol{X}_i) = \frac{e^{\boldsymbol{X_i\beta_j}}}{1+\sum_{k=1}^{J} e^{\boldsymbol{X_i\beta_k}}}$, for j=0, 1, 2,…,J, where $\boldsymbol{\beta_0} = \boldsymbol{0}$, and $\boldsymbol{\beta_j} = \begin{pmatrix} \beta_{j0} \\ \beta_{j1} \\ \vdots \\ \beta_{jm} \end{pmatrix}$

(2) $\boldsymbol{\delta_j} = \frac{dP_j}{d\boldsymbol{X_i}} = P_j[\boldsymbol{\beta_j} - \sum_{k=0}^{J} P_k\boldsymbol{\beta_k}]$

(3) $\text{Relative Risk (Odds Ratio)} = \frac{P_j}{P_k} = \frac{e^{\boldsymbol{X_i\beta_j}}}{e^{\boldsymbol{X_i\beta_k}}} = e^{\boldsymbol{X_i\beta_j}} \quad if \quad k = 0$

(4) $\frac{\text{Relative Risk}_{[\beta_{j0}+\beta_{j1}x_1+\cdots+\beta_{jm}(x_m+1)]}}{\text{Relative Risk}_{[\beta_{j0}+\beta_{j1}x_1+\cdots+\beta_{jm}x_m]}} = \frac{e^{[\beta_{j0}+\beta_{j1}x_1+\cdots+\beta_{jm}(x_m+1)]}}{e^{[\beta_{j0}+\beta_{j1}x_1+\cdots+\beta_{jm}x_m]}} = e^{\beta_{jm}}$

It is difficult to interpret the coefficients $\boldsymbol{\beta_j}$ of the multinomial logit model estimated from equation (1) because it does not provide the marginal effects. There are two options. The first is to provide the marginal effects $\boldsymbol{\delta_j}$, i.e. $\frac{dP_j}{d\boldsymbol{X_i}}$, for each variable (Equation 2). The disadvantage of this method is that it gives the change in the absolute probability of being each mode of transaction due to a one-unit change in the explanatory variable. Since the patents are not equally distributed across the three modes, the absolute marginal effects vary by the number of patents in each mode. The alternative method, which is used here, is to provide the ratio of relative risk. Relative risk (odds ratio) is defined as the ratio of the probability of a patent being licensed or sold to the probability of not being transacted (the reference mode) (Equation 3). The ratio of relative risk is the change of relative risk given a one-unit change in the explanatory variable (the exponent of β_{jm}, Equation 4) (Stata, 2015). Since the relative risk is calculated through dividing the probability of a patent being licensed or sold by the probability of not being transacted, it is possible to compare the ratio of relative risk across the different modes.

The ratio of relative risk can be interpreted as follows. When a ratio of relative risk is greater than 1, a one-unit change in the explanatory variable increases the relative probability of being a specific type of transaction modes versus the probability of no transaction, while a ratio of relative risk below 1 reduces this probability. A ratio of relative risk of 1 occurs when the two probabilities are identical, so that the presence of the explanatory variable has no effect on the outcome.

3.3 Independent variables

We use logarithmic *R&D cost* of a patent reported by the respondent in the inventory survey as a measurement of patent quality[3]. EK GRYU IGRI[RGZK YW[GXK ZKXS UL RUMGX0ZNS0I A 4 IUYZ !*Qua_R&D cost*" ZU ZKYZ ZNK N_VUZNKY0Y (&

!8TYKXZ 50M[XK (NKXK"

A set of dummy variables reflecting firm- and patent-specific strategies are constructed to test hypothesis 2.

We use the questions in the survey related to intellectual property management practice to test hypothesis 3.

3.4 Control variables

We add three sets of control variables into the regression. Firms who answer the questionnaire are classified into large, medium, small and micro companies by their operating revenue and number of employees, though the criteria vary between industries. Based on this classification, we construct three firm size dummy variables large, medium and small and take micro companies as the reference group. To control for the effect of ownership on choice of

[3] 8T KSV0X0IGR YZ[J0KY$ G LK] UZNKX 0TJ0IGZUXY UL VGZKTZ W[GR0Z_ GXK [YKJ Y[IN GY I0ZGZ0UTY$ T[SHKX UL IRG0SY$ LGS0R_ Y0`K$ XGZ0U UL MXGTZKJ ZU L0RKJ VGZKTZY GTJ YU LUXZN !BW[0II0GX0T0 KZ GR&$)'(*"& 30ZGZ0UT 0TLUXSGZ0UT 0Y TUZ G\G0RGHRK LUX ZNK 3N0TKYK VGZKTZY& EK NG\K 0TIR[JKJ ZNK T[SHKX UL IRG0SY 0T ZNK XKMXKYY0UT GY G VXU^_ UL VGZKTZ W[GR0Z_& 7U]K\KX$ ZNK IUKLL0I0KTZY UL ZN0Y \GX0GHRK GXK TUZ YZGZ0YZ0IGRR_ Y0MT0L0IGTZ& CNK XKGYUT SG_ HK GY]NGZ 4GTM GTJ <UZUNGYN0 !)'(*" GXM[KJ$ ZNK GVVR0IGTZY 0T 3N0TG ZKTJ ZU JXGLZ TGXXU] IRG0SY 0T UXJKX ZU NG\K ZNK VGZKTZY MXGTZKJ$]N0IN IUSVXUS0YKJ ZNK W[GR0Z_ UL ZNK VGZKTZ 0T ZNK KTJ& 2GYKJ UT U[X 0TZKX\0K]]0ZN VGZKTZ GMKTZY GTJ GZZUXTK_Y 0T 3N0TG$]K IGT IUTL0XS ZNGZ W[GTZ0Z_ UL IRG0SY 0Y TUZ GT GII[XGZK 0TJ0IGZUX UL VGZKTZ W[GR0Z_ 0T 3N0TG&

transaction modes, we construct three dummy variables state-owned, Hong Kong, Macau and Taiwan-owned (HKMT) and foreign to represent companies' ownership status and take domestic private firms as the reference group. We also construct 31 technology dummies to control for the 32 technologies fields that the patents belong to. The correlation matrixes of the variables are presented in Table 1a and 1b, which show no serious multicollinearity among variables.

!8TYKXZ CGHRKY (G GTJ (H NKXK"

4. Discussion and conclusion

8T ZN0Y YZ[J_$]K IUTYZX[IZ G TU\KR JGZGHGYK H_ SKXM0TM ZNK B8?>%GJS0T0YZXGZKJ 8T\KTZ0UT B[X\K_ JGZGHGYK GTJ 0TIU?GZ JGZGHGYK ZU GTGR_`K ZNK VGZKTZ ZXGTYGIZ0UT SUJKY 0T 3N0TG& EK 0T\KYZ0MGZK]NGZ LGIZUXY 0TLR[KTIK ZNK VXUHGH0R0Z_ UL G VGZKTZ HK0TM R0IKTYKJ UX YURJ \KXY[Y HK0TM K^VRU0ZKJ 0TZKXTGRR_& EK [YK G S[RZ0TUS0GR RUM0Z SUJKR ZU K^GS0TK NU] VGZKTZ W[GR0Z_$ KIUTUS0IGRR_% GTJ GJS0T0YZXGZ0\K%SUZ0\GZKJ VGZKTZ YZXGZKM0KY$ IUXVUXGZK 8? SGTGMKSKTZ YZX[IZ[XK GLLKIZ ZXGTYGIZ0UT SUJKY UL VGZKTZY&

EK L0TJ ZNGZ GRZNU[MN 0T MKTKXGR N0MNKX W[GR0Z_ RKGJY ZU N0MNKX VXUHGH0R0Z_ UL 0T\KTZ0UT VGZKTZ ZXGTYGIZ0UT$ ZNKXK 0Y GT 0T\KXZKJ D%YNGVKJ XKRGZ0UTYN0V HKZ]KKT VGZKTZ W[GR0Z_ GTJ 0T\KTZ0UT VGZKTZaY VXUHGH0R0Z_ ZU HK R0IKTYKJ& CNK LGIZ ZNGZ ZNK RU]%W[GR0Z_ 0T\KTZ0UT VGZKTZY GXK RKYY R0QKR_ ZU HK R0IKTYKJ ZNGT ZNK SKJ0[S%W[GR0Z_ 0T\KTZ0UT VGZKTZY SG_ XKY[RZ LXUS N0MN ZXGTYGIZ0UT IUYZ GYYUI0GZKJ]0ZN ZNK RU]%W[GR0Z_ VGZKTZ$]N0RK ZNK N0MN%W[GR0Z_ 0T\KTZ0UT VGZKTZY GXK RKYY R0QKR_ ZU HK R0IKTYKJ SG_ HK J[K ZU ZNK LGIZ ZNGZ ZNKYK VGZKTZY GXK valuable, rare, inimitable and irreplaceable resources of the company& EK GRYU L0TJ ZNGZ VGZKTZ W[GR0Z_ NGY TU KLLKIZ UT ZNK ZXGTYGIZ0UT UL [Z0R0Z_ SUJKR VGZKTZY$]N0IN SG_ HK J[K ZU ZNK0X 0TLKX0UX W[GR0Z_ 0T IUSVGX0YUT ZU ZNK 0T\KTZ0UT VGZKTZaY&

The invention patents owned by firms which have strategies to cross license patents, block competitors and protect early-stage R&D are less likely to be sold than be kept for internal use. The firms need these invention patents to achieve what we call economically-motivated strategies, which are based on the intrinsic principle of market-oriented economy rather than respond to government intervention. An exception in this regard is the utility model patents applied for and maintained to build portfolio (an economically-motivated strategy) are more likely to be sold. In contrast to the economically-motivated strategies, administratively-motivated patent strategies are defined according to the companies' answer in the questionnaires that they are incentivized by government subsidy to apply for and maintain patents or use patents to pass the certification of high-technology companies to reduce tax rate. We find that the patents are motivated by these strategies are more likely to be sold or licensed. It seems though the companies have made rational choices because they would probably not apply for these patents without incentives from government. Once the objective of obtaining the patents is fulfilled and with the mounting pressure to pay maintenance fee to renew the patents (subsidy does not cover maintenance fee), firms choose to transact the patents.

When it comes to the effect of IP management structure on patent transaction mode, ZNK [ZOROZ_ SUJKR VGZKTZY SGTGMKJ H_ G YVKIOGRO`KJ 8? JKVGXZSKTZ OY SUXK ROQKR_ ZU HK ROIKTYKJ ZNGT ZU HK QKVZ LUX OTZKXTGR [YK& 8L ZNK YVKIOGRO`KJ 8? JKVGXZSKTZ OY [TJKX RKMGR JKVGXZSKTZ$ ZNK [ZOROZ_ SUJKR VGZKTZY GXK SUXK ROQKR_ ZU HK YURJ& >T ZNK IUTZXGX_$ Of an invention patent is managed by a specialized department under the general administration, legal or R&D department, which are mainstream organizations responsible for IP management in China, it is less likely to be sold versus to be kept for internal use.

;GYZ H[Z TUZ ZNK RKGYZ$ XKY[RZY UL YKVGXGZK XKMXKYYOUTY UT OT\KTZOUT GTJ [ZOROZ_ SUJKR VGZKTZY ORR[YZXGZK ZNGZ LOXSY VKXIKO\K ZNK Z]U Z_VKY UL VGZKTZY JOLLKXKTZR_ GTJ K^VRUOZ ZNKS OT JOLLKXKTZ]G_Y& 5UX K^GSVRK$ OT\KTZOUT VGZKTZY YKKS ZU HK SUXK KLLKIZO\K ZNGT [ZOROZ_ SUJKR VGZKTZY OT OSVRKSKTZOTM KIUTUSKZXOIGRR_%SUZO\GZKJ VGZKTZ YZXGZKMOKY Y[IN GY IXUYY ROIKTYOTM$ HRUIQOTM IUSVKZOZUXY GTJ VXUZKIZOTM KGXR_%YZGMK A 4& CNKXKLUXK$ LOXSY]OZN ZNKYK YZXGZKMOKY GXK RKYY ROQKR_ ZU YKRR ZNK OT\KTZOUT VGZKTZY& 3RKGXR_ ZNK JOLLKXKTIK OT W[GROZ_ GTJ GRYU OT VXUZKIZOUT VKXOUJ UL ZNK Z]U Z_VKY UL VGZKTZY GXK OT SOTJ UL IUXVUXGZK SGTGMKXY]NKT ZNK_ IUTYOJKX ZXGTYGIZOUT INUOIKY&

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Table 1a: Correlation Matrix: Regression on Invention Patents

		Mean and Standard Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Qua_R&D Cost	12.03(12.0	1.00																								
2	R&D cost	3.10(1.56)	0.96	1.00																							
3	Firm_cross licensing	0.36(0.48)	-0.1	-0.1	1.00																						
4	Firm_imitation prevention	0.63(0.48)	0.12	0.11	-0.1	1.00																					
5	Firm_corporate image	0.29(0.45)	0.01	0.01	-0.3	-0.0	1.00																				
6	Firm_standard setting	0.28(0.45)	0.08	0.09	-0.1	-0.0	0.07	1.00																			
7	Firm_blocking competitors	0.38(0.48)	-0.0	-0.0	0.38	0.00	-0.2	-0.1	1.00																		
8	Firm_protection of early stage R&D	0.60(0.49)	0.02	0.00	0.06	-0.1	-0.1	0.00	0.19	1.00																	
9	Firm_administrative requirement	0.07(0.25)	0.00	0.00	-0.0	-0.0	0.13	-0.0	-0.1	0.02	1.00																
10	Patent_revenue generation	0.62(0.49)	0.11	0.08	0.06	0.08	-0.0	0.02	0.08	0.02	-0.1	1.00															
11	Patent_cost reduction	0.27(0.45)	-0.0	-0.0	0.13	0.16	-0.0	-0.0	0.07	0.02	-0.0	0.01	1.00														
12	Patent_portfolio building	0.55(0.50)	0.00	0.01	0.04	-0.1	-0.0	-0.0	0.10	0.02	-0.0	-0.2	-0.4	1.00													
13	Patent_government subsidy	0.06(0.24)	0.02	0.02	-0.0	-0.0	0.04	0.07	-0.0	-0.0	0.05	-0.0	-0.1	-0.1	1.00												
14	Patent_qualification certification	0.09(0.29)	0.03	0.03	-0.1	-0.0	0.07	0.03	-0.1	0.03	0.16	-0.2	-0.1	-0.1	0.11	1.00											
15	Patent_corporate image	0.22(0.41)	0.02	0.04	-0.1	0.01	0.17	0.08	-0.1	0.01	0.06	-0.2	-0.1	-0.1	-0.0	0.03	1.00										
16	Specialized department	0.63(0.48)	-0.0	-0.0	0.33	-0.0	-0.2	-0.0	0.24	0.03	-0.1	0.05	0.06	0.13	-0.1	-0.1	-0.1	1.00									
17	General administration department	0.23(0.42)	0.02	0.03	-0.1	-0.0	0.07	0.05	-0.0	-0.1	-0.0	-0.0	-0.0	0.03	0.02	0.04	0.05	-0.1	1.00								
18	Legal department	0.23(0.42)	-0.1	-0.1	0.50	-0.0	-0.2	-0.2	0.32	0.17	-0.1	0.08	0.13	0.00	-0.0	-0.1	-0.1	0.31	-0.3	1.00							
19	R&D department	0.44(0.50)	0.07	0.08	-0.2	0.06	0.11	0.05	-0.2	-0.0	0.12	-0.0	-0.0	-0.0	0.05	0.07	0.07	-0.1	-0.5	-0.4	1.00						
20	Large	0.52(0.50)	-0.1	-0.1	0.26	0.07	-0.0	-0.1	0.23	0.13	0.05	0.00	0.18	-0.0	-0.1	-0.1	-0.1	0.30	-0.2	0.35	-0.0	1.00					
21	Medium	0.27(0.45)	0.16	0.16	-0.1	-0.0	0.05	0.11	-0.1	-0.0	-0.0	0.00	-0.1	-0.0	0.09	0.12	0.05	-0.1	0.03	-0.1	0.09	-0.6	1.00				
22	Small	0.18(0.39)	0.06	0.05	-0.1	-0.0	0.06	0.03	-0.0	-0.1	-0.0	0.01	-0.1	0.02	0.05	0.06	0.06	-0.1	0.28	-0.2	-0.0	-0.5	-0.2	1.00			
23	State-owned	0.19(0.39)	-0.0	-0.0	-0.1	-0.0	0.11	0.01	-0.0	0.10	0.18	-0.1	0.02	-0.0	-0.0	0.07	0.09	-0.1	-0.1	-0.2	0.27	0.18	-0.0	-0.1	1.00		
24	HKMT	0.06(0.24)	0.03	0.04	-0.0	0.01	0.03	0.03	-0.0	-0.0	-0.0	0.01	-0.0	0.02	0.02	0.01	0.00	0.00	0.02	-0.0	-0.0	-0.0	0.07	-0.0	-0.1	1.00	
25	Foreign	0.16(0.37)	-0.1	-0.0	0.07	-0.0	-0.0	0.01	0.02	-0.1	-0.0	-0.0	-0.0	0.06	0.04	-0.0	0.01	0.06	0.17	0.05	-0.0	-0.0	0.01	0.10	-0.2	-0.1	1.00

Table 1b: Correlation Matrix: Regressions on Utility Model Patents

		Mean and Standard Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Qua_R&D cost	9.46(10.8	1.00																								
2	R&D cost	2.69(1.49)	0.96	1.00																							
3	Firm_cross licensing	0.14(0.35)	0.03	0.03	1.00																						
4	Firm_imitation prevention	0.62(0.49)	0.05	0.04	0.02	1.00																					
5	Firm_corporate image	0.43(0.50)	-0.04	-0.04	-0.22	-0.11	1.00																				
6	Firm_standard setting	0.34(0.47)	0.08	0.07	-0.01	-0.09	-0.05	1.00																			
7	Firm_blocking competitors	0.20(0.40)	-0.01	-0.01	0.20	0.13	-0.17	-0.04	1.00																		
8	Firm_protection of early-stage R&D	0.55(0.50)	-0.03	-0.02	-0.03	-0.10	-0.09	0.05	0.01	1.00																	
9	Firm_administrative requirement	0.11(0.31)	-0.03	-0.01	0.06	-0.08	-0.01	-0.07	0.01	0.07	1.00																
10	Patent_revenue generation	0.55(0.50)	0.08	0.06	0.05	0.07	-0.05	0.00	0.07	-0.01	-0.07	1.00															
11	Patent_cost reduction	0.32(0.47)	-0.06	-0.05	-0.05	-0.02	0.01	0.03	-0.04	0.06	0.00	-0.11	1.00														
12	Patent_portfolio building	0.41(0.49)	0.05	0.04	0.10	0.09	-0.05	0.00	0.12	0.06	0.00	-0.18	-0.31	1.00													
13	Patent_government subsidy	0.11(0.31)	0.03	0.03	0.01	-0.05	0.03	0.03	-0.06	-0.04	0.05	-0.06	-0.10	-0.16	1.00												
14	Patent_qualification certification	0.15(0.36)	-0.01	-0.01	-0.04	-0.04	0.03	-0.03	-0.08	0.01	0.12	-0.21	-0.15	-0.10	0.04	1.00											
15	Patent_corporate image	0.30(0.46)	0.01	0.01	-0.05	-0.03	0.12	0.03	-0.04	-0.01	-0.01	-0.21	-0.19	-0.15	-0.07	-0.02	1.00										
16	Specialized department	0.38(0.49)	0.03	0.03	0.12	0.06	-0.10	0.08	0.17	0.04	-0.07	0.05	0.02	0.11	-0.05	-0.10	-0.09	1.00									
17	General administration department	0.29(0.45)	0.04	0.03	-0.08	-0.01	0.06	0.03	-0.09	-0.07	-0.05	0.02	-0.03	-0.05	0.02	0.02	0.02	-0.11	1.00								
18	Legal department	0.05(0.22)	-0.02	-0.01	0.18	0.03	-0.09	-0.01	0.11	0.07	0.05	0.00	-0.04	0.08	-0.04	-0.03	-0.01	0.14	-0.15	1.00							
19	R&D department	0.55(0.50)	-0.03	-0.02	-0.01	-0.01	0.01	-0.06	-0.01	0.06	0.01	-0.01	0.05	0.02	-0.01	0.01	-0.02	0.07	-0.72	-0.21	1.00						
20	Large	0.31(0.46)	-0.11	-0.09	0.12	0.03	-0.10	-0.04	0.15	0.11	0.09	-0.03	0.14	0.03	-0.08	-0.09	-0.07	0.25	-0.24	0.12	0.20	1.00					
21	Medium	0.34(0.47)	0.09	0.08	-0.02	-0.01	0.03	0.00	-0.03	-0.01	0.00	0.00	-0.03	0.04	-0.01	0.04	0.01	-0.03	0.04	-0.01	-0.04	-0.48	1.00				
22	Small	0.32(0.46)	0.03	0.01	-0.09	-0.01	0.06	0.04	-0.11	-0.09	-0.08	0.03	-0.09	-0.06	0.07	0.05	0.05	-0.19	0.17	-0.11	-0.12	-0.46	-0.49	1.00			
23	State-owned	0.17(0.38)	-0.11	-0.08	0.02	-0.06	0.00	-0.09	0.05	0.12	0.13	-0.05	0.09	-0.03	-0.05	-0.02	-0.01	-0.02	-0.15	-0.06	0.16	0.36	-0.08	-0.25	1.00		
24	HKMT	0.06(0.25)	0.03	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.00	0.03	-0.02	0.04	0.00	0.00	-0.06	0.04	0.05	0.05	-0.07	0.00	0.06	-0.05	-0.12	1.00	
25	Foreign	0.09(0.29)	0.03	0.04	0.01	0.04	-0.04	-0.01	0.03	0.02	-0.01	0.01	0.02	0.00	-0.03	0.00	-0.01	0.02	-0.05	0.10	0.01	0.04	0.02	-0.04	-0.14	-0.08	1.00

Table 2a: Ratio of Relative Risk of Patent Transaction Modes: Invention Patents

	!("		!)"		!*"		!+"	
CXGTYGIZ0UT SUJK	;0IKTYKJ	BURJ	;0IKTYKJ	BURJ	;0IKTYKJ	BURJ	;0IKTYKJ	BURJ
@[GFA 4 IUYZ							0.96(0.02)**	1.01(0.01)
A 4 IUYZ	(&(/!'&'+"###	(&'+!'&')"#	(&(-!'&'+"###	(&')!'&')"	(&(-!'&'+"###	(&'+!'&')"##	1.66(0.28)***	0.97(0.08)
50XSFIXUYY R0IKTY0TM	'&./!'&()"	'&.+!'&'-"###	'&/-!'&(+"	'&.)!'&'-"###	'&0'!'&(,"	'&.0!'&'."###	0.90(0.15)	0.79(0.07)**
50XSF0S0ZGZ0UT VXK\KTZ0UT	(&(-!'&(,"	'&/-!'&'-"##	(&'0!'&(+"	'&/-!'&'-"##	(&()!'&(-"	'&0.!'&'."	1.10(0.15)	0.97(0.07)
50XSFIUXVUXGZK 0SGMK	'&0'!'&(*"	'&0-!'&'."	'&0)!'&(*"	'&0,!'&'."	(&'(!'&(,"	'&/*##!'&'."	0.99(0.15)	0.83(0.07)**
50XSFYZGTJGXJ YKZZ0TM	'&00!'&(*"	'&0!'&'."	(&'(!'&(*"	'&0(!'&'."	(&((!'&(,"	'&0)!'&'."	1.11(0.15)	0.92(0.07)
50XSFHRUIQ0TM IUSVKZ0ZUXY	(&()!'&(,"	'&/)!'&'-"###	(&(.!'&(-"	'&/(!'&'-"###	(&(0!'&(."	'&--!'&',"###	1.18(0.17)	0.66(0.05)***
50XSFVXUZKIZ0UT UL KGXR_%YZGMK A 4	(&('!'&(+"	'&.(!'&',"###	(&('!'&(+"	'&.'!'&',"###	(&)(!'&(."	'&./!'&'-"###	1.20(0.17)	0.78(0.06)***
50XSFGJS0T0YZXGZ0\K XKW[0XKSKTZ	'&0,!'&)*"	'&/*!'&(("	'&0(!'&))"	'&/.!'&(("	'&00!'&),"	'&00!'&(*"	0.98(0.24)	0.99(0.13)
?GZKTZFXK\KT[K MKTKXGZ0UT	(&()!'&(."	'&0/!'&'/"	(&'0!'&(-"	'&0.!'&'/"	(&''!'&(-"	'&0'!'&'."	0.99(0.15)	0.90(0.07)
?GZKTZFIUYZ XKJ[IZ0UT	(&'/!'&(."	(&('!'&'0"	(&'-!'&(."	(&(+!'&('"	(&('!'&(/"	(&()!'&("	1.08(0.18)	1.12(0.1)
?GZKTZFVUXZLUR0U H[0RJ0TM	'&/(!'&()"	(&(-!'&'0"#	'&.0!'&()"	(&()!'&'0"	'&./!'&(*"	(&((!'&("	0.78(0.13)	1.11(0.1)
?GZKTZFMU\KXTSKTZ Y[HY0J_	'&0.!'&),"	(&+-!'&(/"##	(&''!'&)-"	(&*0!'&(."###	(&'*!'&)."	(&*(!'&(."##	1.03(0.27)	1.31(0.17)**
?GZKTZFW[GR0L0IGZ0UT IKXZ0L0IGZ0UT	'&//!'&)"	(&(-!'&(*"	'&/+!'&)'"	(&('!'&()"	'&/)!'&)'"	(&'(!'&()"	0.83(0.2)	1.01(0.12)
?GZKTZFIUXVUXGZK 0SGMK	(&'.!'&(."	(&)(!'&("##	(&'*!'&(."	(&)(!'&('"##	'&0/!'&(."	(&('!'&('"	0.99(0.17)	1.10(0.10)
BVKI0GR0`KJ JKVGXZSKTZ	(&(*!'&(,"	(&',!'&'."	(&((!'&(,"	(&'(!'&'."	(&'0!'&(-"	'&0/!'&'/"	1.09(0.16)	0.97(0.08)
6KTKXGR GJS0T0YZXGZ0UT JKVGXZSKTZ	'&-(!'&()"##	(&'0!'&()"	'&-+!'&(*"##	'&00!'&(("	'&.+!'&(."	'&-.!'&'/"###	0.74(0.17)	0.67(0.08)***
;KMGR JKVGXZSKTZ	'&-0!'&(,"	'&/)!'&("	'&0'!'&))"	'&.,!'&('"##	'&0*!'&),"	'&.,!'&(("##	0.91(0.25)	0.76(0.11)**
A 4 JKVGXZSKTZ	'&/(!'&(+"	'&0/!'&("	'&/*!'&(+"	'&0(!'&'0"	'&0-!'&(0"	'&/'!'&'0"##	0.96(0.19)	0.8(0.09)**
;GXMK					'&.-!'&*+"	'&),!'&',"###	0.75(0.33)	0.25(0.05)***
<KJ0[S					'&,*!'&)+"	'&*.!'&'."###	0.52(0.23)	0.37(0.07)***
BSGRR					'&-+!'&)0"	'&*+!'&'-"###	0.62(0.28)	0.34(0.06)***
BZGZK%U]TKJ					'&,*!'&('"###	(&'+!'&(("	0.54(0.11)**	1.04(0.11)
7:<C					'&/(!'&))"	'&.)!'&()"##	0.82(0.22)	0.72(0.12)*
5UXK0MT					'&-/!'&(,"#	(&,!'&(+"###	0.71(0.16)	1.49(0.14)***
CKINTURUM_ 4[SS0KY	=UZ 0TIR[JKJ		8TIR[JKJ		8TIR[JKJ		8TIR[JKJ	
=[SHKX UL >HYKX\GZ0UTY	('$+-+		('$+-+		('$'*+		('$'*+	
;UM ;0QKR0NUUJ	%+/,*&0*		%+.+,&-'		%+*.*&+'		%+*.'&*	

Notes: The data in parentheses refer to standard errors. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

Table 2b: Ratio of Relative Risk of Patent Transaction Modes: Utility Model Patents

	!("		!)"		!*"	
CXGTYGIZ0UT SUJK	;0IKTYKJ	BURJ	;0IKTYKJ	BURJ	;0IKTYKJ	BURJ
A 4 IUYZ	'&0!'&'-"	'&0.!'&'+"	'&0'!'&'-"	'&0,!'&'+"	'&/0!'&'-"	'&0/!'&'+"
50XSFIXUYY R0IKTY0TM	(&+-!'&*,"	(&(,!'&(/"	(&-*!'&+'"##	(&(/!'&(0"	(&-+!'&+)"#	(&'0!'&(/"
50XSF0S0ZGZ0UT VXK\KTZ0UT	'&/'!'&(,"	(&',!'&()"	'&/'!'&(,"	(&'/!'&()"	'&0(!'&(0"	(&(,!'&(+"
50XSFIUXVUXGZK 0SGMK	'&.0!'&(-"	(&'*!'&()"	'&/'!'&(-"	(&'*!'&()"	'&/,!'&(/"	(&'/!'&(*"
50XSFYZGTJGXJ YKZZ0TM	'&/+!'&(."	(&(0!'&(*"	'&/.!'&(/"	(&)'!'&(*"	'&0-!'&)'"	(&)-!'&(,"##
50XSFHRUIQ0TM IUSVKZ0ZUXY	(&)*!'&)."	'&0'!'&(*"	(&))!'&)."	'&0'!'&(*"	(&),!'&)0"	'&/+!'&()"
50XSFVXUZKIZ0UT UL KGXR_ YZGMK A 4	(&(-!'&))"	(&')!'&(("	(&(,!'&))"	(&'(!'&(("	(&(0!'&),"	'&0)!'&(("
50XSFGJS0T0YZXGZ0\K XKW[0XKSKTZ	'&0+!'&)0"	(&'/!'&(/"	'&0/!'&*'"	(&(+!'&(0"	(&'+!'&*)"	'&0.!'&(."
?GZKTZFXK\KT[K MKTKXGZ0UT	(&)/!'&)."	'&0)!'&(("	(&*(!'&)/"	'&0*!'&()"	(&-*!'&*."##	'&0/!'&(*"
?GZKTZFIUYZ XKJ[IZ0UT	(&*,!'&*("	(&(-!'&(-"	(&*(!'&*("	(&(/!'&(-"	(&*-!'&**"	(&('!'&(-"
?GZKTZFVUXZLUR0U H[0RJ0TM	(&+*!'&*)"	(&+'!'&(/"###	(&+)!'&*)"	(&+!'&(/"##	(&+*!'&*+"	(&+,!'&)'"###
?GZKTZFMU\KXTSKTZ Y[HY0J_	(&,/!'&+,"	'&0-!'&(/"	(&-(!'&+-"	'&0-!'&(/"	(&/,!'&,+"##	'&0+!'&(0"
?GZKTZFW[GR0L0IGZ0UT IKXZ0L0IGZ0UT	(&),!'&*,"	(&**!'&)'"	(&)-!'&*,"	(&*-!'&)("##	(&,*!'&++"	(&+.!'&)*"##
?GZKTZFIUXVUXGZK 0SGMK	'&0.!'&)*"	(&((!'&(,"	'&0-!'&)*"	(&(+!'&(,"	'&.0!'&)("	(&(*!'&(-"
BVKI0GR0`KJ JKVGXZSKTZ	(&+-!'&)0"#	(&(*!'&(*"	(&+/!'&)0"##	(&(,!'&(*"	(&,'!'&*)"#	(&('!'&(*"
6KTKXGR GJS0T0YZXGZ0UT JKVGXZSKTZ	'&+0!'&(+"##	(&**!'&)-"	'&,(!'&(,"##	(&*-!'&)."	'&-)!'&)'"	(&**!'&)/"
;KMGR JKVGXZSKTZ	'&*.!'&(0"#	)&+.!'&,/"###	'&++!'&))"	)&.(!'&-+"###	'&+/!'&),"	)&./!'&-/"###
A 4 JKVGXZSKTZ	'&,.!'&(+"##	(&,)!'&)."##	'&,-!'&(+"##	(&,*!'&)."##	'&-*!'&(/"	(&**!'&),"
;GXMK					(&),!'&.0"	)&'0#!'&/-"
<KJ0[S					'&00!'&-("	(&+)!'&,."
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CKINTURUM_ 4[SS0KY	=UZ 0TIR[JKJ		8TIR[JKJ		8TIR[JKJ	
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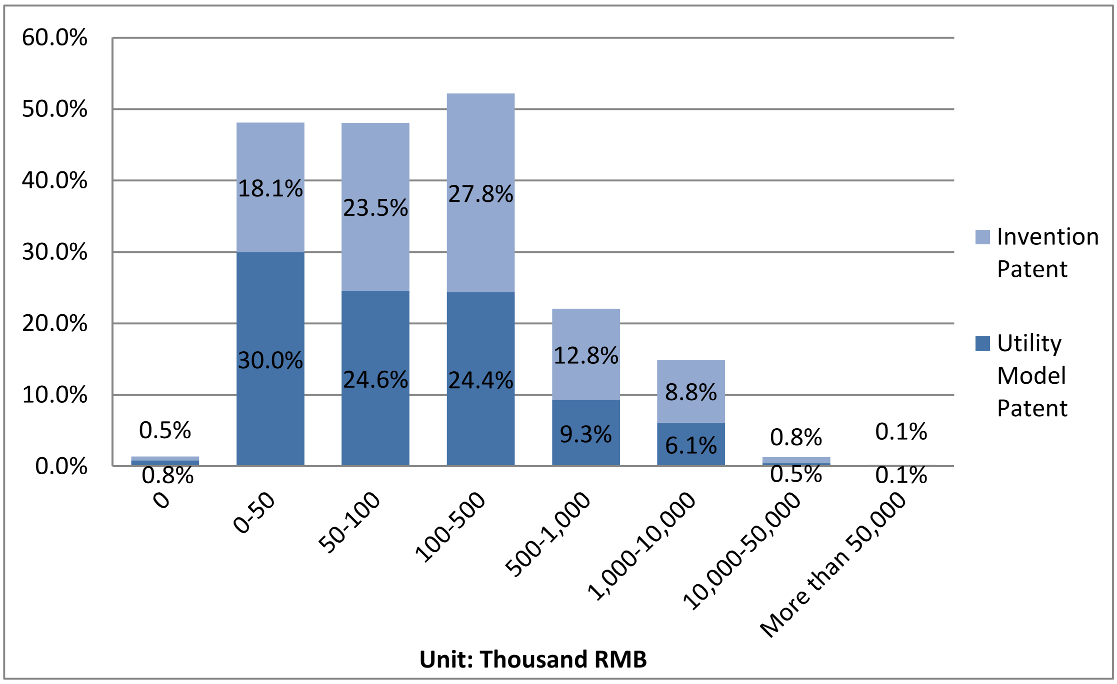
Notes：The data in parentheses refer to standard errors. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%

Figure 1: Distribution of R&D cost of Invention and Utility Model Patents (Unit: Thousand RMB)



How do Chinese Firms Benefit from R&D Internationalization in Europe Developed Economies? Exploring the moderating roles of Absorptive Capacity and Entry Mode of firms

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School of Management, Zhejiang University[1]

Abstract:

This study examines the contingent relationship between firms' R&D internationalization in developed economies and the innovation performance of parent firms in emerging economies. Incorporating perspectives of reverse knowledge transfer and signaling effect, we propose that, the reverse knowledge inflows from the foreign R&D subsidiary and the positive signal released during the process of R&D internationalization can facilitate the parent firm's innovation performance. In addition, the positive relationship is more likely to occur when the parent firms possess an adequate level of absorptive capacity or when the foreign R&D subsidiary adopts a partially owned entry mode. Results using a sample of Chinese firms which have undertaken R&D internationalization in Europe provide support for these arguments. These findings contribute to our knowledge of the complicated relationship between R&D internationalization and innovation performance and have important practical implications.

Key words: R&D internationalization·Innovation performance·Absorptive capacity·Entry mode·Emerging economies

1. Introduction

In the past few decades, there has been an increasing tendency for multinational enterprises (MNEs) to internationalize their R&D activities (Penner-Hahn & Shaver, 2005; Yang et al., 2014). Extant research on R&D internationalization has addressed a wide range of issues including the motives (Todo et al., 2009; Von Zedtwitz et al., 2002), the development of modes (Gassmann & von Zedtwitz, 1999; Minin & Zhang, 2010) and the outcomes of R&D internationalization (Hsu et al., 2014; Chen et al., 2012; Iwasa & Odagiri, 2004). Particularly, the topic of the impact of a firm's R&D internationalization on its innovation performance is an increasingly significant relevant research agenda (Hsu et al., 2014; Chen et al., 2012; Belderbos et al., 2014). Extant literature mostly sets in the context of firms from developed economies (Iwasa & Odagiri, 2004; Singh, 2008) and the relationship between R&D internationalization

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and innovation performance is rather complicated(Penner-Hahn & Shaver, 2005; Belderbos et al., 2014; Singh, 2008). On one hand, R&D internationalization contributes to the innovation performance of either parent firms in home countries or R&D facilities in host countries (Penner-Hahn & Shaver, 2005; Belderbos et al., 2014; Hsu et al., 2014; Chen et al., 2012). On the other hand, high levels of R&D internationalization will lead to problems of coordination, communication and monitoring (Grassman & von Zedtwitz, 1999) and expose the firm to an increased level of liability of foreignness (Zaheer, 1995; Thomas, 2006).

In this study, we want to explore this relationship in a different research scenario where the R&D internationalization is undertaken by firms from emerging economies. Empirically, notwithstanding the increasing trend of R&D internationalization is more salient in emerging economies today (Di Minin & Zhang, 2010, 2012; Awate et al., 2012, 2014), there is less empirical evidence in current research specifically to go into the relationship in emerging economies. Theoretically, the motivation and the process of R&D internationalization of firms from advanced economies and emerging economies are different (Awate et al., 2014), and therefore make the aforementioned relationship even more elusive in the context of emerging economies. Therefore, exploring the relationship between R&D internationalization and innovation performance of firms from emerging economies to advanced economies could be equally intriguing (Awate et al., 2012, 2014).

To fill this research gap, we draw on reverse knowledge transfer (Amobos et al., 2006; Rabbiosi, 2011) and signal theory (Spence, 1973; Stiglitz, 2000; Connelly et al. 2011; Sanders & Boivie, 2004) to explore how Chinese firms' R&D internationalization in European developed economies affects their innovation performance. Drawing on these two theoretical perspectives, we argue that we need to check the contingent relationship between R&D internationalization and innovation performance from both the knowledge/signal source party and recipient party. In this study, we mainly focus on two factors which affect the transfer of reverse knowledge inflows and the strength of signals: (1) the parent firm's absorptive capacity and (2) the entry mode of the foreign R&D subsidiary. In doing so, our study makes two important contributions. First, our study adds to the literature on R&D internationalization research by incorporating two new and important theoretical perspectives: reverse knowledge transfer and signaling effect. Second, our study extends extant research of the effect of firm's R&D internationalization on its innovation performance by going beyond the direct role of R&D internationalization in firm innovation performance as previous research did (Penner-Hahn & Shaver, 2005; Thomas, 2006; Chen et al., 2012) and exploring the moderating roles of both parent firm's absorptive capability and foreign R&D facility's entry mode.

2. Theoretical background and hypotheses

2.1 R&D internationalization from emerging economies to developed economies

The R&D internationalization of firms from emerging economies is actually a springboard to realize their catch-up strategy (Awate et al., 2014; Luo & Tung, 2007) , emerging economy firms go overseas to access to critical technological resources and competencies that redress their own resource gaps (Rui &Yip, 2008). Accordingly, emerging economy firms' R&D internationalization investments, particularly in developed economies, are often knowledge accessing in nature (Awate et al., 2014).

Because of the technology gap between emerging economies and advanced economies, emerging economy firms are more likely to experience a lower technology level than that of foreign R&D subsidiaries (Awate et al., 2014). Therefore, the direction of knowledge flow is "reverse"(Hakanson & Nobel, 2001; Zhou & Frost, 2003; Mudambi et al., 2014). Recent literature has noticed that reverse knowledge transfer has significant profits for the headquarters at home (Ambos et al., 2006; Rabbiosi, 2011). Firstly, subsidiaries tap into the host-location-specific sources of knowledge (Foss & Pedersen, 2002; Hakanson & Nobel, 2001). Second, through the modification of knowledge in response to the demands of particular markets (Li & Zhou, 2008), the parent firms upgrade their existing technology(Hansen, 1999; Tsai, 2001) . This further helps the firms to achieve the trade-off between firms' technology exploration in host countries and exploitation of knowledge developed at home (Hsu et al., 2014) .

Institutional voids are a prevailing condition permeating emerging economies (Peng, 2003; Tan & Meyer, 2011). Spence (1973) argues that one party can use observable mechanisms to demonstrate its unobservable characteristics, serving as a signal. It is suggested in weak institutional environments, firms must use additional ways as signals to convey information about their capabilities (Connelly et al. 2011; Sanders & Boivie, 2004). We argue that R&D internationalization works to improve firm's technological capability in an indirect way, which is attributed to the signaling effect. As latecomers, the establishment of an international R&D facility is a powerful proof of the firm's strength in technological catching up and international operation. Specifically, R&D internationalization in developed economies is a strong signal to relevant stakeholders of firm's power and prospects(Soh et al., 2004). Therefore, it will help the firm to attract more innovation resources. Besides, the signal also help the firm to gain more support from the government, including subsidy, tax preference. As a result, it helps to ease financial constraint and get access to diverse sources of knowledge and facilitating consequently the firm's innovation performance(e.g. Katila & Shane, 2005\).Based on these arguments, we propose that:

Hypothesis 1: R&D internationalization in developed economies is positively related with the innovation performance of firms from emerging markets.

2.2 Moderating effect of parent's absorptive capability

During the process of knowledge transfer, it would never be one party's responsibility to propel the knowledge flow, but depends on both the knowledge source party and the recipient party (Cummings & Teng, 2003). According to Gupta and Govindarajan (2000), the target recipient's capacity to absorb incoming knowledge is a prime factor. By such analogy, headquarters' absorptive capacity plays a vital role to ensure the effective reverse knowledge transfer (Ambos et al., 2006; Mudambi et al., 2014).

Absorptive capability is defined as “an ability to recognize the value of new information, assimilate it, and apply it to commercial ends” (Cohen & Levinthal, 1990; p. 128). In order to capitalize on knowledge acquisition from external sources, firms need a considerable level of absorptive capacity. Accordingly, we posit that parent firm’s absorptive capacity will moderate the relationship between R&D internationalization and innovation performance. Firstly, firms with strong absorptive capacity are able to assess, screen and recognizethe value of knowledge more critically (Ambos et al., 2006). Secondly, a higher level of absorptive capacity help firms assimilate and applicate the valuable knowledge from foreign R&D facilities to develop new products(Kotabe et al., 2011) and cross-fertilization with domestic R&D stock. Thirdly, parent firm’s absorptive capacity allows it to accomplish the trade-off between exploration in host countries and exploitation exploitation of knowledge developed at home more effectively(Ambos et al., 2006).

In the perspective of signaling effect, with a higher level of absorptive capacity, the firm can better response to the feedback effect of the signal, which can help the firm better leverage and integrate the diverse sources from relevant stakeholders and fully utilize the positive signaling effect of R&D internationalization. Thus, we formulate:

Hypothesis 2: The parent firm’s absorptive capacity strengthens the effect of R&D internationalization in developed economies on firm’s innovation performance from emerging economies.

2.3 Moderating effect of foreign R&D facility’s entry mode

Foreign market entry mode choice plays a vital role because it determines the firm’s degree of resource commitment to the foreign market (Quer, et al., 2007; Hill et al., 1990), the risks the firm will bear in the host country (Xu et al., 2004), the valuable knowledge and skills the firm will access in host countries (Richards & Yang, 2007), the level of control a firm can exercise over its foreign activities (Anderson & Gatignon, 1986), and the level of internal integration and external local embeddedness (Buckley et al., 2003). Hence, we argue that the ownership structure of the foreign R&D subsidiary will play an important role in the effect of R&D internationalization on firm’s innovation performance.

First, the ownership structure of the foreign subsidiary will affect the level of liability of foreignness and local embeddedness (Buckley et al., 2003; Xu et al., 2004; Lu & Xu, 2006), which will in turn affect the access to valuable resources in local environment . For the partially owned subsidiary, its status as partly a child of a local firm can contribute to a reduced level of foreignness and a higher level of local legitimacy (Xu et al., 2004; Lu & Xu, 2006), thus it will be easier for the foreign facility to access diverse sources of valuable local knowledge and skills in the local environment. Moreover, the local partner also plays a role as a “conduit” to access local R&D experts(Wang & Liu, 2013; Gomes-Casseres, 1990). Conversely, in a wholly owned mode, liability of foreignness and lack of external legitimacy hinders the acquisition of technology from the local environment. In addition, highly controlled foreign facility becomes a relatively closed entity in the local markets In this respect, partially-owned subsidiaries are superior in the knowledge acquisition in the process of R&D internationalization.

Secondly, partially owned subsidiary enables more interaction with the local partner, thus, making it possible for partners to readily access, share each other's various technologies and operating skills (Pak & Park, 2004; seng & Lee, 2010). In contrast, under the wholly owned ownership structure, it cannot utilize the knowledge inflows to improve the innovation performance without the knowledge spillover through the interaction.

Thirdly, as for the signaling effect, entry mode will also affect the strength of the signal. For partially owned subsidiary, the signal of firm’s capability evaluation is stronger than that for wholly owned mode. Stakeholders will believe that those firms are more likely to success in innovation and worth more investment. While for the wholly owned ones, it send the signal that the foreign partner needs to rely on its own capability to research and develop solely. Based on the discussions above, we propose that:

Hypothesis 3: The entry mode of foreign R&D subsidiary moderates the relationship between R&D internationalization in developed economies and emerging economy firm’s innovation performance. Specifically, the positive relationship will be strengthened for subsidiary using the partially owned entry mode.

3. Methodology

3.1 Sample and data collection

The trend of increasing R&D internationalization is more salient in emerging economies. China, the world’s largest emerging economy, provides an excellent research setting to test our hypotheses above. We constructed a dataset of R&D internationalization in Europe (2003-2013) by firms listed on the Shanghai and Shenzhen Stock Exchanges of China. We referred to the website of Ministry of Commerce of China (MCC) to get the international R&D investment information. We then manually collected information on overseas subsidiaries of listed firms from annual reports and announcements. We finally confirmed the list of firms that had R&D internationalization projects in European Countries.

Table 1 shows the detailed information. Our sample includes 59 Chinese firms that have made one or more R&D internationalization projects in 14 European countries over the period 2003-2013 across 17 industries. The total number of observations in the full sample is 77, among which, 14% of them are through acquisition, the others are through the greenfield investment. We find that in our full sample, among the 77 R&D internationalization projects are invested in developed European countries. As shown in Table 1, Germany, Netherlands and Italy are among the top destinations.

---Insert Table 1 about here---

3.2 Measures

Innovation performance. Patent counts have been often used to measure innovation performance in previous studies (e.g., Henderson & Cockburn, 1996; Penner-Hahn & Shaver, 2005; Awate et al., 2012). Consistent with these previous studies, in our study, innovation performance was measured as the count of granted patents of a firm in a given year. In this study, we focus on the firm level innovation performance of the parent firm in home country. In order to smooth the difference across firms and industries, we use the natural logarithm of patent counts.

R&D Internationalization. We use the international R&D investment ratio (the amount of a particular R&D internationalization investment/ total asset of the firm) as a proxy of R&D internationalization (Asaba, 2013; Kor, 2006).

Absorptive capacity. Following the majority extant studies (e.g. Cohen & Levinthal, 1989; Belderbos, 2003), absorptive capacity is measured as R&D Intensity of the parent firm (the ratio of R&D expenditures to the firm's total sales).

Foreign entry mode. We use a dummy variable, which took the value of 1 if the subsidiary was a wholly owned ownership and 0 if it was a partially owned ownership. Consistent with the literature, we categorized subsidiaries that were more than 90% owned by the Chinese parent firm as a wholly owned ownership (Mani, Antia, & Rindfleisch, 2007).

Control variables. We adopted eight firm-level-specific variables to control for their potential impact on firm innovation performance. In accordance with previous studies (e.g. Hsu et al., 2014; Lu et al., 2014), we controlled firm size, which was measured as the natural logarithm of firm's total number of employees (Chan & Makino, 2007; Brouthers & Dikova, 2010). We controlled firm age as older firms tend to be more inert (Hannan & Freeman, 1984), leading to being less innovative than younger ones. Firm age was measured as the number of years since the establishment of the parent (Chen et al., 2012; Hsu et al., 2014). We controlled the effect of IPO by using the IPO age that was measured as the number of years since the parent's initial public offerings. The firm's slack resources were controlled for because slack resource can increase exploratory search and enhance innovation performance (Tan & Peng, 2003). This construct was measured as the firm's current ratio (Zahra & Hayton, 2008) calculated as its current assets to current liabilities (Zahra, 1991).

We also controlled the degree of internationalization. Following previous studies (Tallman & Li, 1996; Pan et al., 2014), we measure the degree of internationalization as the ratio of foreign sales to total sales. We also include return on asset and the natural logarithm long term investment as control variables. Finally, we controlled for government equity share, defined as equity shares owned by government agencies.

Previous studies found that cross-national institutional distance affect firms' overseas investments (Holburn & Zelner, 2010; Martin et al., 2010). We controlled the potential institutional distance effects on firm innovation performance. To operationalize this construct, we firstly choose among well-recognized institutional environment indicators which are directly related to investment risks of inward FDI. We adopt the widely used Worldwide Governance Indicator (WGI)2 constructed by Kaufmann, Kraay, and Mastruzzi (2009) from the website of World Bank (2013). Then we used the method developed by Kogut and Singh (1988) to represent the construct of institutional distance using the following index:

$$ID_{jt} = \sum_{i=1}^{6} \{(I_{ijt} - I_{ict})^2 / V_{it}\} / 6$$

where ID_{jt} stands for the index for the j th institutional dimension of j country in year t, V_{it} is the variance of the index of i th dimension in year t, c indicates China, and ID_{jt} is the institutional difference of the j th country from China in year t.

R&D internationalization can be divided into research-oriented R&D and support oriented R&D (Ito & Shimizutani, 2007; Shimizutani & Todo, 2008). For different type of international R&D activities, the knowledge a firm acquired and transferred are different, thus leading to different spillover effects on innovation performance. So we control for this effect by adding a dummy variable which is coded 1 if the foreign facility functions as a research-oriented R&D subsidiary and 0 otherwise.

Additionally, we control for industry-level and sub-national level characteristic which may have potential heterogeneity in estimations using 2-digit SIC code dummies and the Chinese Marketization Index developed by Fan et al. (2011).

Since there might exist a time lag from the establishment of international R&D activities until these activities affect firm's innovation performance. So all the values for the independent variables and the moderating variables of the model lagged those for the dependent variable by one year to take consideration of the time-lag effect, as well as to avoid potential endogeneity.

[2] The Worldwide Governance Indicators (WGI) are a research dataset summarizing the views on the quality of governance provided by a large number of enterprise, citizen and expert survey respondents in industrial and developing countries. WGI comprises six dimensions, Voice and Accountability ,Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption, respectively.

4. Analyses and results

Descriptive analysis results of variables are presented in Table 2. Table 3 presents the regression results. Model 1 includes only controls and the main effects of R&D internationalization, and Model 2 adds the moderating effects of parent firm's absorptive capacity and foreign R&D facility's entry mode. Model 3 and Model 4 adds interaction terms (R&D internationalization*absorptive capacity, R&D internationalization*foreign entry mode) respectively. Model 5 adds two interactions. Prior to creating the interaction terms, variables were mean-centered in order to reduce the potential problem of multicollinearity (Aiken & West, 1991). Before estimating the regression model, we did a test for potential multicollinearity and found that variance inflation factors (VIF) value was below 3 for all variables, much below the 10 rule of thumb signaling the presence of multicollinearity (Neter, Wasserman, & Kutner, 1990).

In Model 1, the coefficient for R&D internationalization is negative but not significant (β=-0.150, $P>0.1$). Thus, Hypothesis 1 is not supported. The results in model 3 show that the coefficient for the interaction term of R&D internationalization and absorptive capacity is positive and statistically significant (β=0.740, $P<0.01$). To facilitate interpretations, we plotted the results in Figure.1 as shown in Figure.1, for parent firm with a high level of absorptive capacity, R&D internationalization has a positive relationship with firm's innovation performance; for parent firm with a low level of absorptive capacity, this relationship becomes negative. Based on the approach suggested by Aiken and West (1991), the simple slopes associated with the two lines in Figure.1 were calculated. For parent firm with a high level of absorptive capacity, the simple slope is 0.978, which is significantly different from zero at the level of $P<0.05$. In contrast, for parent firm with a low level of absorptive capacity, the simple slope is 0.652, which is not significantly different from zero ($P>0.1$). Thus, Hypothesis 2 receives support from the results.

The results in model 4 show that the coefficient for the interaction term of R&D internationalization and entry mode is negative and statistically significant (β= -0.930, $p<0.05$). To facilitate interpretations, we plotted the results in Figure.2. As shown in Figure.2, for foreign R&D subsidiary using a partially owned entry mode, R&D internationalization has a positive relationship with firm's innovation performance; for foreign R&D subsidiary using a wholly owned entry mode, this relationship becomes negative. We also did simple slope analysis. For foreign R&D subsidiary using a partially owned entry mode, the simple slope is 2.392, which is significantly different from zero at the level of $P<0.1$. In contrast, for parent firm using a wholly owned entry mode, the simple slope is -3.413, which is also significantly different from zero ($P<0.05$). Thus, Hypothesis 3 was supported. In the full model (Model 5), the coefficients of the two moderating effects (β=0.738, $P<0.01$ for interaction of R&D internationalization and parent firm's absorptive capacity; β= -0.934, $P<0.1$ for interaction of R&D internationalization and foreign R&D subsidiary's entry mode) stays consistent with the model 3 and model 4, specifically. Thus, Hypothesis 2 and Hypothesis 3 further receive support from the results.

---Insert Table 2 and Table 3 about here---

Robustness tests

We have undertaken supplementary analyses to ensure the robustness of our findings. First, we used another measurement for the variable of innovation performance. We use the original form of patent counts as a dependent variable in our supplementary analyses. Since the patent counts is a nonnegative, integer count variable, we employ non-linear estimators including the negative binomial estimation regression method and Poisson regression model (Greene, 2003). The results did not change. Second, for robustness checks, we used longer lags. While due to the limited size of our sample, we only lagged our explanatory for two years in our supplementary analysis, the results show that the direction of the coefficients of the main explanatory variables keep consistent, but they are all not significant. Third, for the concern that one firm invested two or more R&D internationalization projects in a given year, which may lead to the potential bias of the results. We randomly select one project for the firms which have two or more projects in a given year. Thus, we limited our sample size to 67 observations and then re-estimated our models. Results of these models are consistent with those reported in Table 3.

5. Discussion and Conclusion

5.1 Discussions

MNEs rely on multiple geographical sources of knowledge to benefit from them through knowledge transfer(Ambos et al., 2006) . This trend is salient even among MNEs from emerging economies, which are latecomers to R&D globalization compared to U.S. and European firms (Asakawa, 2001; Song et al., 2011; Di Minin & Zhang, 2010). Few studies have examined the relationship between R&D internationalization and the innovation performance of emerging economy firms. We examined the R&D internationalization strategy of emerging economy firms dawning on the perspective of reverse knowledge transfer and signaling effect. We proposed that the parent firm's absorptive capacity and the foreign R&D subsidiary's entry mode moderate the relationship between R&D internationalization and parent firm's innovation performance. Our results provide general support for these arguments.

More specifically, our results indicate that the relationship between R&D internationalization and firm's innovation performance is more complicated in the context of emerging economies. While we did not find direct evidence to support for the positive relationship between R&D internationalization in developed economies and innovation performance of emerging economy firms, we find that the effect of R&D internationalization on innovation performance lies on the parent firm's absorptive capacity as well as the ownership-based entry mode of the foreign subsidiary. This implies that the positive effect of R&D internationalization on innovation performance of firms can not automatically occur, but largely depends on firms' internal factors and efforts such as absorptive capacity and foreign entry mode. This echoes the inconsistent findings from existing literatures (Zaheer, 1995; Schmidt & Sofka, 2006; Singh, 2008; Hsu et al., 2014). First, our findings show that, by owning a higher level of absorptive capacity, the parent firm at home can better leverage the benefits obtained from the investment of international R&D, thus broadening its knowledge base and technological capability. Second, our results indicate the important role of the foreign subsidiaries' entry mode in the relationship between R&D internationalization and innovation performance. Interestingly, we find that in the process of R&D internationalization, if the foreign R&D subsidiary adopts a wholly owned ownership structure, the benefits of the reverse knowledge transfer and the signaling effect will be mitigated.

5.2 Theoretical Contributions and Managerial Implications

Our study makes several contributions to our knowledge of the impact of firm R&D internationalization on innovation performance. First, this study adds literature on R&D internationalization research by incorporating two new and important theoretical perspectives: reverse knowledge transfer and signaling effect. Existing research have mainly examined firms from advanced economies from competence exploitation perspective (Cantwel & Mudambi, 2005, 2011), our study adds to the line of research focused on the R&D internationalization from emerging markets (Hsu et al. 2014; Di Minin & Zhang, 2010; Di Minin et al., 2012) from the perspective of reverse knowledge transfer and signaling effect, showing that, MNEs from emerging economies can indeed benefit from the investment of R&D internationalization in developed economies.

Second, our study deepen our understanding of the conditions under which R&D internationalization in developed economies influences the innovation performance of emerging economy firms. Due to the complicated relationship between firm R&D internationalization and innovation performance (Cantwel & Mudambi, 2005; Penner-Hahn & Shaver, 2005; Belderbos et al., 2014; Thomas, 2006; Chen et al., 2012; Hsu et al., 2014), especially in the context of emerging economies, we not only check the direct role of R&D internationalization in firm innovation performance, but also examines how the above role varies across different strategic contexts. On the one hand, our study contributes to our knowledge of the role of parent firm's absorptive capacity in the process of R&D internationalization. On the other hand, while existing research implies that WOS is more easy for headquarter and the subsidiary to develop a shared language and routines (Steensma & Corley, 2001), we find the opposite evidence, which is, the partially owned entry mode can help the parent firm benefit more.

Our study also has some important managerial implications. First, this study suggests two ways for firms from emerging economies to benefit from the process of R&D internationalization. One way is to improve and accumulate the absorptive capacity of the parent firm. The other way is to carefully selecting an appropriate entry mode for the foreign R&D subsidiary.

5.3 Limitations and Future Research

this study has some limitations. First, the inherent deficiencies of the data sample impose some limitations, for example the unavailability of the new products performance data. Future study may do some more surveys to complement this measurement. Second, due to the specific direction setting in European developed countries, the sample used in this study limits the external validity of the conclusions. Future studies should extend our sample in other countries like America or Japan and even other emerging countries. Third, since we only take consideration of the firms with R&D internationalization activities, which may cause a potential selection bias for our model. In the future, we should expand our sample to firms without R&D internationalization activities.

Table 1 Descriptions of R&D internationalization in Europe of sampled firms in the period 2003–2013

	Number of projects	%		Number of projects	%
Destination of R&D internationalization			**Industry of internationalization**		
Germany	22	28.57	Electronics and communication	19	24.68
Netherlands	12	15.58	Special-purpose equipment manufacturing	17	22.08
Italy	11	14.29	Software and information service	11	14.29
England	7	9.09	Automotive	11	14.29
Denmark	5	6.41	Others	19	24.68
Finland	4	5.19	**Size (employees) of parent firms**		
France	4	5.19	More than 2000	48	62.34
Russia	4	5.19	500-2000	27	35.06
Switzerland	2	2.60	Less than 500	2	2.60
Luxembourg	2	2.60	**Firm ownership type**		
Poland	2	2.60	State-owned firms	25	32.47
Slovakia	1	1.30	Private firm	46	59.74
Belgium	1	1.30	Others	6	7.79

Investment of R&D internationalization(US $m)			**Foreign entry mode**		
More than 50	7	9.09	Wholly owned subsidiaries	67	87.01
10-50	6	7.79	Partially owned subsidiaries	10	12.99
5-10	9	11.69	Greenfield investment	67	87.01
Less than 5	55	71.43	Acquisition	10	12.99
Time of R&D internationalization			**R&D type of foreign subsidiary**		
2003-2006	6	7.79	Research oriented R&D	10	12.99
2007-2010	33	42.86	Support oriented R&D	67	87.01
2011-2013	38	49.35			

Table 2 Descriptive statistics and correlations

Variable	Mean	S.	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Innovation	2.55	1.9													
2. R&D	0.01	0.0	-0.32*												
3. Absorptive capacity	0.03	0.0	-0.14	0.11											
4. Foreign entry mode	0.86	0.3	-0.23*	0.12	0.14										
5. Export intensity	0.28	0.2	-0.25*	0.12	0.10	0.28*									
6. R&D type	0.15	0.3	0.19	-0.09	-0.27	0.05	-0.18								
7.Firm age	11.24	5.0	0.02	0.15	-0.14	-0.05	0.10	0.19							
8. IPO age	4.66	3.4	-0.29*	0.21*	0.25*	0.17	0.19	-0.05	0.32*						

9. Firm size	8.17	1.0	0.57**	-0.36*	-0.26	-0.18	-0.36*	0.35*	0.18	-0.30*				
10. ROA	0.06	0.0	-0.04	0.04	0.13	0.11	-0.13	0.05	-0.13	0.09	-0.06			
11. Slack resources	1.83	1.9	-0.24*	0.25**	0.24*	-0.12	-0.05	-0.08	-0.03	0.30**	-0.32*	0.32*		
12.Government equity	0.18	0.2	0.32**	-0.11	-0.04	-0.16	-0.40*	0.30*	0.01	-0.34*	0.28**	0.05	0.02	
13. Long term investment	14.89	7.6	0.11	0.01	-0.21	0.04	-0.24*	0.16	0.50*	0.01	0.29**	-0.09	-0.0	0.27*
14. Home country	9.23	1.9	-0.17	-0.09	-0.03	-0.08	0.36**	-0.13	-0.09	-0.02	-0.20	-0.03	0.04	-0.18	-0.0
15. Institutional distance	3.84	1.5	0.05	-0.06	0.11	0.27*	0.00	-0.02	-0.10	0.14	0.04	0.11	0.11	-0.09	-0.0

*p<0.1; **p<0.05; ***p<0.01

Table 3 Regression analysis results of innovation performance

	Innovation performance (Log(Number of Patents))					Innovation performance (Number of Pate	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6 (Negative binomial)	Model (Poisso
Explanatory Variables:							
R&D internationalization	-0.15	-0.159	0.207*	0.650*	1.021**	4.014**	9.442
	(5.5430)	(5.5480)	(0.4250)	(1.3240)	(1.5200)	(1.7730)	(4.683
Absorptive capacity		0.196	0.836***	0.163	0.794***	1.213**	1.374*
		(7.2470)	(0.3360)	(6.8300)	(0.3300)	(0.4940)	(0.481
Foreign entry mode		-0.153	-0.177	-0.750***	-0.774***	-2.114***	-4.316
		(0.6900)	(0.7390)	(0.5470)	(0.6250)	(0.6050)	(1.839
R&D internationalization				-0.930**	-0.934*	-8.058***	-17.60

*foreign entry mode				(2.5950)	(2.9200)	(2.7450)	(7.759
R&D OFDI*absorptive capacity			0.740***		0.738***	4.332***	5.798*
			(1.0040)		(0.9410)	(1.5460)	(1.879
Control Variables:							
Export intensity	-0.003	0.034	0.007	0.017	-0.005	-0.818	0.247
	(0.8130)	(0.8420)	(0.8310)	(0.8410)	(0.8150)	(0.8260)	(1.067
R&D type	-0.071	0.004	0.008	0.013	0.02	0.286	0.717
	(0.6830)	(0.7350)	(0.7180)	(0.7200)	(0.7020)	(0.5480)	(0.317
Firm age	0.003	-0.015	-0.071	-0.052	-0.109	-0.097	-0.146
	(0.0590)	(0.0568)	(0.0564)	(0.0578)	(0.0563)	(0.0677)	(0.058
Ipoage	0.02	0.026	0.08	-0.011	0.034	0.0399	-0.217
	(0.0640)	(0.0624)	(0.0614)	(0.0646)	(0.0649)	(0.0628)	(0.084
Firm size	0.412***	0.381***	0.277**	0.379***	0.291**	0.838***	1.025*
	(0.2130)	(0.2360)	(0.2440)	(0.2320)	(0.2480)	(0.2990)	(0.271
Return on assets	-0.103	-0.103	-0.058	-0.101	-0.062	-3.519	-1.02
	(4.5460)	(4.4690)	(4.8650)	(4.3570)	(4.7180)	(3.0390)	(5.549
Slack	0.023	0.006	0.055	-0.171	-0.124	-0.228	-0.45
	(0.1280)	(0.1240)	(0.1100)	(0.1250)	(0.1300)	(0.1670)	(0.315
Government ownership share	0.169	0.089	0.045	0.07	0.032	0.552	0.212
	(1.0780)	(1.1890)	(1.3670)	(1.2040)	(1.3720)	(0.8940)	(0.853
Long term investment	-0.055	0.026	-0.015	0.034	0.004	-0.0386	0.052
	(0.0389)	(0.0405)	(0.0403)	(0.0413)	(0.0401)	(0.0345)	(0.035
Home country institutions	-0.088	-0.099	-0.182	-0.113	-0.186	-0.122	-0.091
	(0.1080)	(0.1130)	(0.1200)	(0.1180)	(0.1230)	(0.1440)	(0.091
Host country institutions	0.02	0.041	-0.029	0.036	-0.029	-0.073	-0.05
	(0.1350)	(0.1380)	(0.1400)	(0.1330)	(0.1320)	(0.1610)	(0.108
SIC Dummy	Included	Included	Included	Included	Included	Included	Includ
Constant						1.382	0.262
						(3.9890)	(2.412

Log likelihood						-297.023	-1788.0
R^2/Pseudo R^2	0.459	0.488	0.523	0.514	0.549		0.695
adj. R^2	0.292	0.305	0.339	0.327	0.363		

Significance: *p<0.1; **p<0.05; ***p<0.01*

Standard errors in parentheses

Note: the coefficients in Model 1, 2, 3, 4 are all standardized.

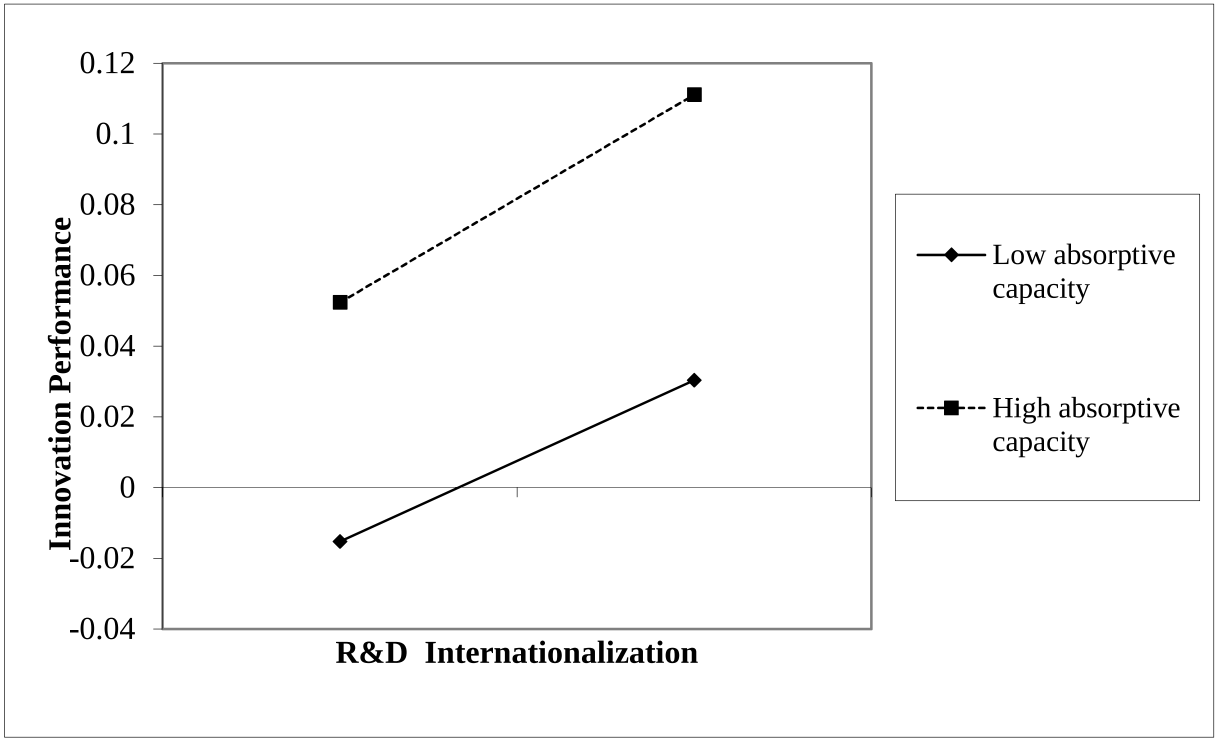

Figure.1 The moderating role of parent firm’s absorptive capacity on the R&D internationalization-innovation performance relationship

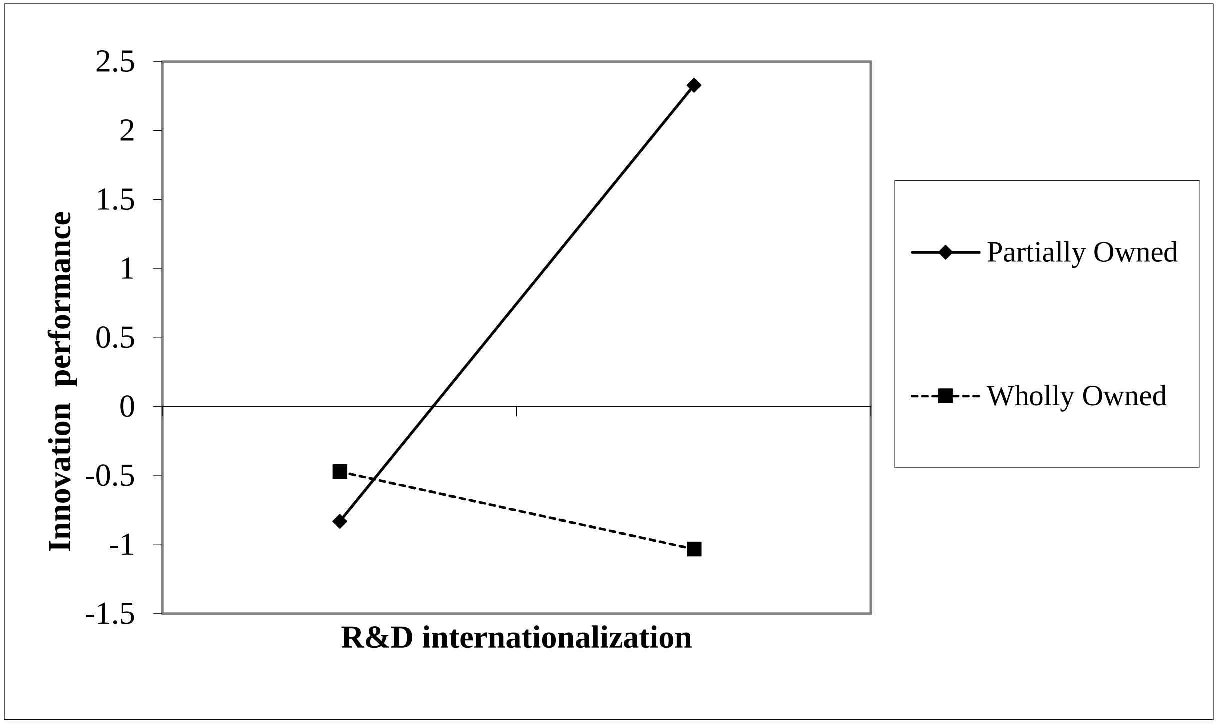

Figure.2 The moderating role of foreign R&D subsidiary's entry mode on the R&D internationalization-innovation performance relationship

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