Kersten, Wolfgang (Ed.); Blecker, Thorsten (Ed.); Ringle, Christian M. (Ed.)

Proceedings

Digitalization in Supply Chain Management and Logistics: Smart and Digital Solutions for an Industry 4.0 Environment

Proceedings of the Hamburg International Conference of Logistics (HICL), No. 23

Proceedings of the Hamburg International Conference of Logistics (HICL) – 23

Wolfgang Kersten, Thorsten Blecker and
Christian M. Ringle (Eds.)

Digitalization in Supply Chain Management and Logistics

HICL

HICL Proceedings

Editors: Kersten, W., Blecker, T., Ringle, C.M. and Jahn, C. 2017
Digitalization in Supply Chain Management and Logistics
Digitalization in Maritime Logistics and Sustainable Supply Chain Management.

Editors: Kersten, W., Blecker, T. and Ringle, C.M. 2015
Innovations and Strategies for Logistics and Supply Chains ISBN 978-3-7375-6206-5
Sustainability in Logistics and Supply Chain Management ISBN 978-3-7375-4057-5
Operational Excellence in Logistics and Supply Chains ISBN 978-3-7375-4056-8

Editors: Kersten, W., Blecker, T. and Ringle, C.M. 2014
Innovative Methods in Logistics and Supply Chain Management IS BN 978-3-7375-0341-9
Next Generation Supply Chains *ISBN 978-3-7375-0339-6*

Editors: Kersten, W., Blecker, T. and Ringle, C.M. 2013
Pioneering Solutions in Supply Chain Performance Management ISBN 978-3-8441-0267-3
Sustainability and Collaboration in Supply Chain Management ISBN 978-3-8441-0266-6

Editors: Kersten, W., Blecker, T. and Ringle, C.M. 2012
Managing the Future Supply Chain ISBN 978-3-8441-0180-5
Pioneering Supply Chain Design ISBN 978-3-8441-0181-2

…find more proceedings on https://hicl.org/publications

Proceedings of the Hamburg International Conference of Logistics (HICL)
23

Digitalization in Supply Chain Management and Logistics

Smart and Digital Solutions for an Industry 4.0 Environment

Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Thorsten Blecker
Prof. Dr. Christian M. Ringle
(Editors)

Edition	1st edition, September 2017
Publisher	epubli GmbH, Berlin, www.epubli.de
Editors	Wolfgang Kersten, Thorsten Blecker, Christian M. Ringle
Cover (Photo)	Nick Scheerbart – unsplash.com/@nck
Layout	Johannes Beyrich, Niels Hackius, Henriette Porten, Sven Reimers
ISBN	978-3-7450-4328-0
ISSN (print)	2635-4430
ISSN (online)	2365-5070

Contents

Preface

This year‘s edition of the HICL proceedings are released at a time of a profound shift: Digitalization puts existing business models to the test and questions existing business processes and logic. Companies find themselves in an increasingly volatile environment and face an ever-increasing demand for flexibility. Logistics and supply chain management shape these processes and long for innovative concepts to achieve the requirements of the digital age.

The dense interweaving of the physical and digital space, of course, poses new risks with regards to data security and creates new requirements with respect to data exchange and acquisition. In contrast, it creates millions of opportunities to optimize, to become more flexible and to reduce risks in supply chains.

This book focuses on the hot topics of digitalization in the supply chain. It contains manuscripts by international authors providing comprehensive insights into topics like risk management, cybersecurity, the internet of things or Blockchain and provides future prospects for the field of supply chain management. All manuscripts contribute to theory development and verification in their respective area of research.

We would like to thank the authors for their excellent contributions, which advance the logistics research progress. Without their support and hard work, the creation of this volume would not have been possible.

Hamburg, October 2017

Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Thorsten Blecker
Prof. Dr. Christian M. Ringle

Part I

Innovation and Technology Management

Blockchain in Logistics and Supply Chain: Trick or Treat?

Niels Hackius[1], Moritz Petersen[2]

1 – Hamburg University of Technology

2 – Kühne Logistics University

Blockchain is an emergent technology concept that enables the decentralized and immutable storage of verified data. Over the last few years, it has increasingly attracted the attention of different industries. Especially in Fintech, Blockchain is hyped as the silver bullet that might overthrow today's payment handling. Slowly, the logistics and supply chain management community realizes how profoundly Blockchain could affect their industry. To shed light on this emerging field, we conducted an online survey and asked logistics professionals for their opinion on use case exemplars, barriers, facilitators, and the general prospects of Blockchain in logistics and supply chain management. We found most of our participants are fairly positive about this new technology and the benefits it offers. However, factors like the hierarchical level, Blockchain experiences, and the industry sector have a significant impact on the participants' evaluation. We reason that the benefits over existing IT solutions must be carved out more carefully and use cases must be further explored to get a rather conservative industry, like logistics, more excited about Blockchain.

Keywords: Blockchain; Logistics; Supply Chain Management; Use Cases

1 Introduction

Blockchain is everywhere. Invented by Satoshi Nakamoto, one or more mysterious individuals unmasked until today, it has been more of an insider's tip for the longest part of its existence. It became known to a larger audience in September 2015: nine financial companies – Goldman Sachs, Barclays, J.P. Morgan, and others – joined forces to build a new Blockchain-based infrastructure for financial services (Underwood 2016). By then, Blockchain had become the latest hype in Fintech, with almost daily announcements of new startups and corporate projects. It took longer until the logistics and supply chain management (SCM) community caught on and slowly realized the impact Blockchain might have on their industry. One major promise of Blockchain is to create transparency – every member of the network has access to the same data, providing a single point of truth (Tapscott & Tapscott 2016). Supply chain transparency is one of the most important and hardest to achieve improvement areas for logistics and SCM (Abeyratne & Monfared 2016). It comes as no surprise that some logistics experts consider Blockchain to offer "enormous potential" (O'Marah 2017), to be a "much-needed platform for economic renewal" (Casey & Wong 2017), and to "transform the supply chain and disrupt the way we produce, market, purchase and consume our goods" (Dickson 2016). Taken together, Blockchain might be nothing less than the "holy grail" (Popper & Lohr 2017). However, as it often is the case with emerging technology, the hype around Blockchain seems primarily driven by technology providers, consultants, and journalists. Logistics operators – especially small and medium-sized companies – declare to have little knowledge about Blockchain (Kersten et al. 2017). This can be explained through the novelty of the technology but also through the lack of convincing use cases that clearly show Blockchain's benefit over existing IT solutions. Logistics and SCM research on Blockchain is still in its infancy (Zhao et al. 2016) and ought to look into possible applications (Yli-Huumo et al. 2016).

The research questions for this paper emerge: *"What might be suitable applications for Blockchain technology in logistics and SCM?"* and *"Should Blockchain in logistics and SCM be considered a treat or rather a trick?"* The remainder of the paper is structured as follows: First, we summarize the basic features of Blockchain. Then, we introduce four use case exemplars explored in theory and practice. Subsequently, we present the findings of an international survey we conducted within the logistics industry to look into the prospects of the four use cases and expectations and apprehensions towards Blockchain. We conclude by discussing the findings and daring a prognosis on the future of Blockchain in the logistics industry.

2 Basics of Blockchain

The Blockchain is a distributed digital ledger of transactions that cannot be tampered with due to the use of cryptographic methods (Pilkington 2016). This short explanation includes the three most important properties of a Blockchain: decentralized, verified, and immutable (see Figure 1). (1) It is decentralized because the network is entirely run by its members, without relying on a central authority or centralized infrastructure that established trust. To add a transaction to the ledger, the transaction must be shared within the Blockchain's peer-2-peer network. All members keep their own local copy of the ledger. (2) It is verified because the members sign the transactions using public-private-key cryptography before sharing them with the network. Therefore, only the owner of the private key can initiate them. However, the members can stay anonymous because the keys are not linked to real-world identities. (3) It is immutable through its consensus algorithm: One or more transactions are grouped together to form a new block. All members of the network can verify the transactions in the block. If no consensus on the validity of the new block is reached, the block is rejected. Likewise, if consensus exists that the transactions in the block are valid, the block is added to the chain. A cryptographic hash is generated for each block. Each block not only holds transaction records but also the hash of the previous block. This creates a block interdependency linking up to a chain – the Blockchain. Altering a

Figure 1: Basic Properties of Blockchain

transaction on the Blockchain retroactively would require not only to alter the local records on most of the networks members' devices but also altering the cryptographic hash of every block down the chain.

A distributed system, like a Blockchain, holds benefits over centralized architectures as it provides the same, verified information to all network members. It creates trust between the parties by eliminating the need for trust. Blockchain can record the transfer of assets between two parties, without the need of a trusted intermediary. Such assets could be digital money, but also carbon credits or other deeds of ownership (Tapscott & Tapscott 2016).

The Bitcoin Blockchain is the first implementation of the Blockchain principles and only supports simple transactions. It also shows how reliable Blockchain is, as it has run error-free since January 2009 and has a current market capitalization of over 35 bn. Euro. Centralized infrastructures, on the contrary, are increasingly hacked – classic middlemen, like banks or dating websites, provide ample examples (Tapscott & Tapscott 2016). Today, many more advanced Blockchain implementations exist. While most are open to the public (permissionless), there are also private (permissioned) Blockchain implementations, where the rights to read and write are controlled by a central authority (Pilkington 2016). Some Blockchain implementations support so-called "smart contracts" or applications living on the Blockchain (Christidis & Devetsikiotis 2016). Smart contracts are conditions written in code. The delivery of a parcel can serve as a simple example: To counter the risk of a loss, a smart contract can be designed such that the payment by the sender is only released once the shipping company confirms the delivery. This allows for a transaction to be automated, yet documented and controlled.

Of note, Blockchain provides not only benefits but also has challenges attached to it (Petersen et al. 2016; Yli-Huumo et al. 2016; Xu 2016). Most result from the early maturity phase of the technology. While these challenges (e.g., limited throughput) have to be addressed from a technological perspective, they should not distract possible users from evaluating the benefits of the underlying principles.

3 Blockchain in Logistics and SCM

As introduced, Blockchain is considered to offer large potential for improving processes and enhancing business models in logistics and SCM. However, accord-

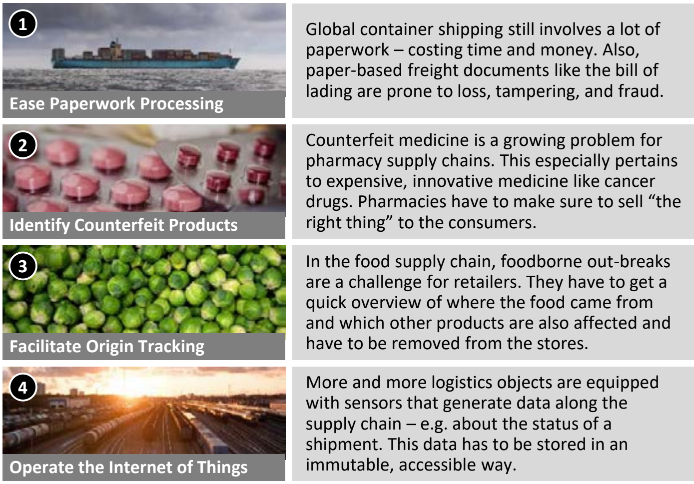

Figure 2: Overview of Use Case Exemplars

ing to a recent study on trends in logistics and SCM, Blockchain is only known to some logistics experts and even fewer pursue implementation plans (Kersten et al. 2017). In this section, we shed light on Blockchain's potential through introducing use case exemplars. These exemplars represent four major ideas currently explored in both theory and practice. They are also four single ideas out of a yet unmapped sea of opportunities. In choosing them, we tried to collate a broad and multifaceted picture later used for investigating the prospects of Blockchain for logistics and SCM. Figure 2 summarizes the use case exemplars. They are introduced in more detail in the following sections.

3.1 Ease Paperwork Processing in Ocean Freight

International container transports have a long trail of paperwork associated with them. For example, shipping refrigerated goods from East Africa to Europe requires stamps and approvals from around 30 people and organizations that must interact with each other on over 200 occasions. Also, documents like the bill of lading might be subjected to fraud (Popper & Lohr 2017). Taken together, the cost of the trade-related paperwork processing is estimated to be between 15 and 50 percent of the costs of the physical transport (Groenfeldt 2017; Popper & Lohr 2017). To tackle such process inefficiencies and digitize paper records, IBM and Maersk joined forces in 2015. They eventually settled for a permissioned Blockchain solution as means to connect the vast global network of shippers, carriers, ports, and customs. The implementation details still must be worked out. However, a round of pilots in 2017 has succeeded. In these pilots, every relevant document or approval was shadowed on the Blockchain, meaning the legacy IT systems were not replaced but augmented. Using a standardized interface, every partner is empowered to have full visibility of the container status (Allison 2017). Until the end of 2017, Maersk hopes to shadow one in seven of their container shipments on the Blockchain – around 10 million boxes per year (Groenfeldt 2017). The problems associated with extensive paperwork are not limited to this specific use case but hamper all kinds of trade flows (Chu et al. 2016; Morabito 2017).

3.2 Identify Counterfeit Products

The provenance of high-value items often relies on paper certificates that can get lost or tampered with: whether a diamond's certificate is genuine or fake – and if the diamond was stolen – is not always easy to determine. The same holds true for expensive wine, watches, or handbags (Lomas 2015). Since, for example, a diamond's serial number can easily be cut, the startup Everledger takes an alternative approach and records 40 data points that uniquely identify a diamond. Using these publicly available records on the Blockchain, a potential buyer can clearly determine if the seller is the actual owner of the diamond and can also make sure he is not buying a "blood diamond" mined in a war zone (Underwood 2016). Everledger plans to extend this fraud detection system into a provenance platform for many high-value items (Lomas 2015). In the medical sector, counterfeit drugs are a known problem that – for example with anti-cancer drugs – can even have lethal consequences if patients do not receive the treatment as prescribed (Mackey & Nayyar 2017). Blockchain could improve patient safety through establishing supply chain transparency from manufacturers through wholesale and pharmacies to the individual patients. Through barcodes or auto ID technology, patients could be empowered to check whether they received the actual drugs (DeCovny 2017; Mackey & Nayyar 2017). Blockchain is considered to make it much more difficult to tamper with products or to channel in products of illegal origin (Sutherland et al. 2017; Apte & Petrovsky 2016; Morabito 2017).

3.3 Facilitate Origin Tracking

If faced with a foodborne disease outbreak, retailers have a hard time figuring out where the bad ingredients came from and to which stores they were delivered (Tian 2016). Today, it can take weeks to track down the source of the contamination and restore consumers' confidence in food safety (Popper & Lohr 2017). To facilitate origin tracking for food items, Walmart partnered with IBM in 2016. Like with Maersk, Blockchain is used to augment the supply chain partners' existing IT systems through a transparent, superordinate ledger, tracking the movements of food items. This shared forum is considered a substantial improvement over Walmart's earlier trials involving barcodes or auto ID technology – solutions that required central databases and trust between the participants (Hackett 2016). In some first pilots, Walmart and IBM digitally tracked both domestic movements – pork from small Chinese farms to Chinese stores – and international movements – produce from Latin America to stores in the United States (Popper & Lohr 2017). In these pilots, data like the farm origin, batch numbers, factory and processing data, expiration dates, and shipping details were written on the Blockchain and instantly became available to all network members. With a foodborne disease outbreak, this data enables Walmart to track down the origin in a matter of seconds. During the year, further pilots with more data attributes are scheduled. Ultimately, Walmart believes Blockchain could also reduce food waste if the newly available data on shelf life is used as a parameter for supply chain optimization (Shaffer 2017).

3.4 Operate the Internet of Things

The Internet of Things (IoT) means everyday objects – essentially everything with a plug – get equipped with electronics and can exchange data over the internet. A Gartner report estimates there will be over 20 billion connected things by 2020 (Gartner 2015). However, the current internet architecture with its server infrastructure might not handle such an amount of devices and data (Eastwood 2017). Single servers represent a single point of failure and raise data security concerns. The public Blockchain ledger is considered a solution to connect and manage IoT devices reliably (Pilkington 2016; Christidis & Devetsikiotis 2016). Given the large amount of possible IoT objects (vehicles, shipments, etc.), logistics might be one of the most promising applications for IoT and Blockchain (Zheng et al. 2017). First large companies start to work in this area. For example, Walmart was recently granted a patent that aims at improving last mile logistics through connecting delivery drones to the Blockchain (Hackett 2017). Such IoT devices connected to the Blockchain could also be provided with a digital currency. This would enable them to interact autonomously with other parties and – through smart contracts – to pay fees and duties by themselves, e.g., for priority access to restricted air corridors (Christidis & Devetsikiotis 2016; Petersen et al. 2016).

4 Survey about the Prospects of Blockchain in Logistics and SCM

To investigate how experts from the logistics industry evaluate Blockchain, we designed and conducted an online survey. This section describes its setup and the most important findings.

4.1 Setup and Data Collection

The survey was implemented using Typeform and had four major parts: First, we inquired the participants' general knowledge of logistics and SCM and Blockchain. Second, we introduced the four use case exemplars and inquired the participants' evaluation of Blockchain benefits and adoption likeliness. Third, we asked the participants about their general opinion on the main beneficiaries of Blockchain in logistics, likely adoption barriers, and the expected effect on established logistics processes. Finally, we inquired job and company details.

We collected the data between April 28th and June 13th, 2017. Participants were mainly recruited through social media, e.g., posts in logistics and Blockchain interest groups on LinkedIn, Xing, or Meetup. The BVL (Bundesvereinigung Logistik e.V.) shared our call for participants through their social media channels. We incentivized participation through small donations. After data collection was concluded, we donated 50 Euro to "Zeit für Zukunft" (Hamburg-based mentoring program) and 50 Euro to "Ingenieure ohne Grenzen" (Berlin-based aid organization) on behalf of our participants.

Especially for anonymous internet surveys, thoroughly examining the data is advised to identify careless responses (Meade & Craig 2012). We excluded three out of 155 initially collected data sets from the analyses due to clear answer patterns or answers that made no sense. Then, we prepared the data for statistical analysis following the guidelines of Hair et al. (2009). We used IBM SPSS Statistics 22 for the analyses.

4.2 Findings

We present the results of the study in the following, mainly through providing the mean values of the participants' evaluations. If our analyses proved them to be statistically significant at the 5%-level, we present more detailed findings and explore the differences between groups of participants.

Figure 3 shows an overview of the 152 participants: The clear majority works in consulting, followed by logistics services and sciences. More than half of the participants come from Germany, followed by the US, Switzerland, and France. Most participants work for small and medium-sized companies with a headcount of under 250 people and an annual turnover of less than USD 50m. This distribution is mainly caused by a high number of participants from small consulting companies. If considered on their own, around 60% of the participants from the logistics services industry work for large companies with over 3.000 employees and more than USD 500m turnover.

We then asked the participants about their company's stance towards Blockchain. Figure 4 summarizes the results. 43% declare they do not look into Blockchain just yet or observe the development from a distance. 37% of the participants investigate use cases, and 20% have implemented first Blockchain solutions. Again, this distribution is caused by consulting companies as almost three-quarters of them either investigate or implement Blockchain solutions. Looking at the logistics services companies alone, around 65% declare to be – if at all – watching from a distance. Only two experiment with Blockchain technology – one start-up and one logistics services behemoth.

Next, we introduced the four use case exemplars. We provided the information in Figure 2 and asked the participants to evaluate each use case regarding (1) the benefit of Blockchain and (2) the likeliness of adopting Blockchain. Figure 5 summarizes the findings through the mean values and standard deviations. Overall, Blockchain is evaluated to offer considerable benefits for all use cases (between

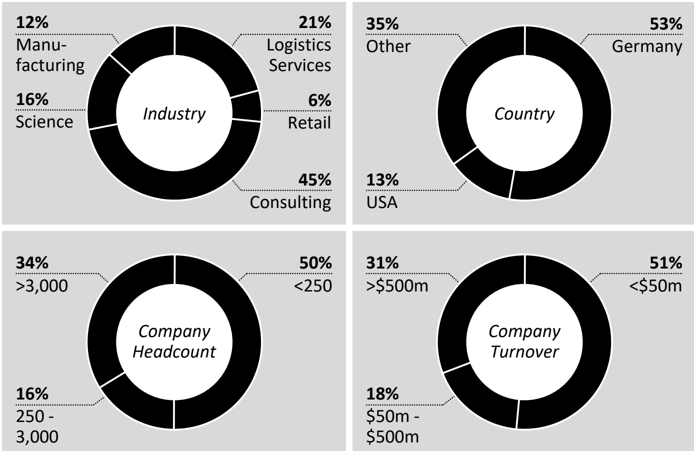

Figure 3: Overview of Participants and their Companies

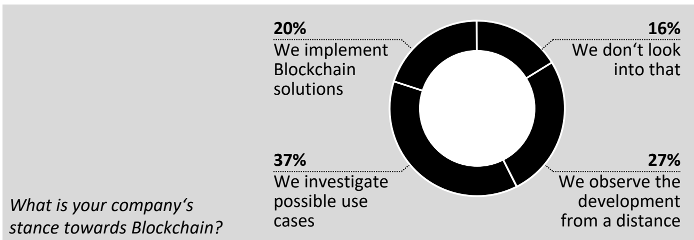

Figure 4: Company’s Stance towards Blockchain

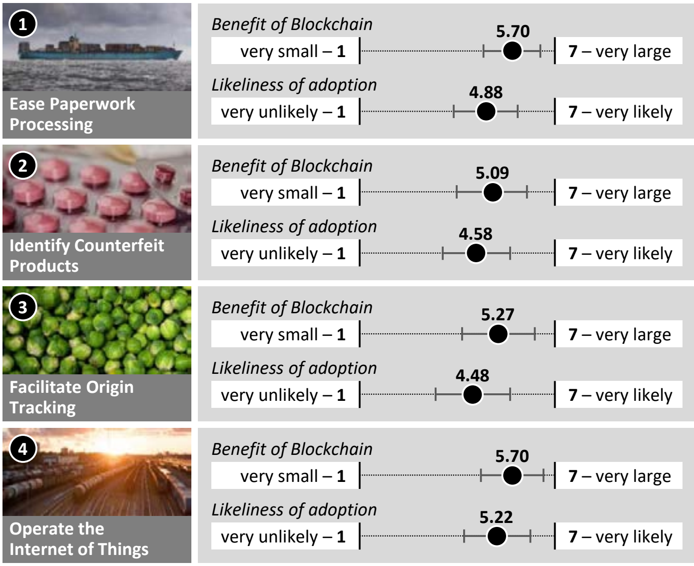

Figure 5: Evaluation of Use Cases

5.09 for the second and 5.70 for the first and fourth use case). In all instances, the likeliness of adoption receives lower ratings than the benefit (between 4.48 for the third and 5.22 for the fourth use case). However, the opinions are not uniform across different groups of participants. Middle managers rate both benefit and adoption likeliness lower than c-level executives do across all four use cases. Also, participants more experienced in Blockchain applications (for example, through own implementations) give better ratings than participants that only think about Blockchain. Finally, the participants' sector is also a differentiator. Especially regarding paperwork processing though Blockchain applications, employees from logistics service providers are more skeptical about the actual benefit than consultants or scientists.

After evaluating the use cases, we inquired the participant's opinion about the main beneficiaries of Blockchain applications in logistics. The findings are shown

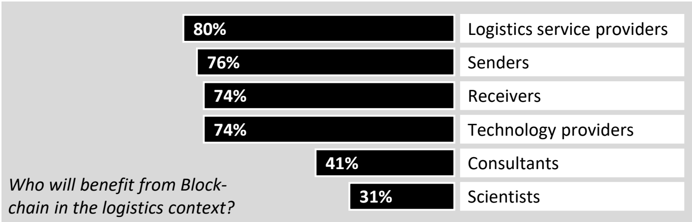

Figure 6: Beneficiaries of Blockchain

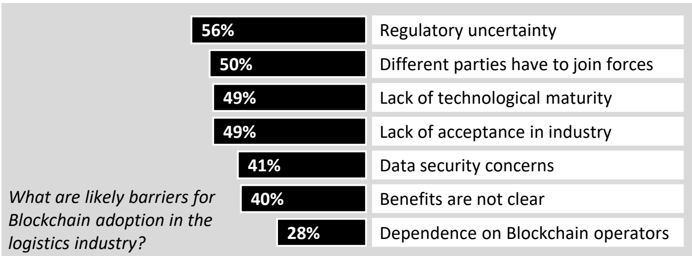

Figure 7: Barriers to Blockchain Adoption

in Figure 6. Around three-quarters of the participants expect logistics service providers, senders, receivers, and technology providers to benefit. Only 41% see consultants and only 31% see scientists as being beneficiaries. Again, these results are influenced by factors like hierarchical level or sector. Only one in five middle managers believes consultants will benefit from introducing Blockchain, while more than half of the c-level executives from the sample share this opinion. Further, a disproportionately high share of employees from logistics service providers believes technology providers will benefit, while consultants focus more on supply chain actors like senders and receivers.

We asked the participants about likely barriers to Blockchain adoption in the logistics industry. Figure 7 summarizes the findings. For 56% of the participants, regulatory uncertainty might be a barrier. Around half of the participants also refer to the fact that different parties must join forces, a lack of technological

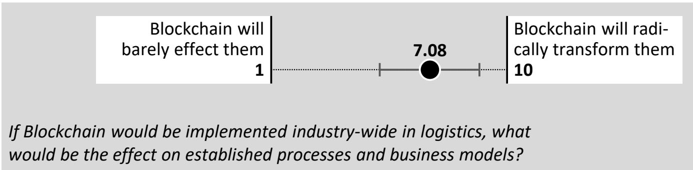

Figure 8: Effect on Processes and Business Models

maturity, and a lack of acceptance in the industry as major barriers. Data security concerns (41%), unclear benefits (40%), and too much dependence on Blockchain operators (28%) are also named to be likely showstoppers. Again, the individual opinions significantly depend on factors like the hierarchical level, the sector, and the participants' experience with Blockchain.

Finally, we inquired the participants' overall evaluation of Blockchain's effect on established processes and business models in logistics. The result is shown in Figure 8. With an average evaluation of 7.08, the participants believe Blockchain would have a strong effect on the industry, even though the transformation might not be as radical as some trade press articles herald. No big differences can be found between any of the groups. The size of the standard deviation (1.88) proves there are skeptics and enthusiasts in the sample. However, they cannot be assigned to a specific group, like consultants or early adopters of Blockchain.

5 Discussion and Implications

Our study revealed valuable insights about Blockchain adoption in the logistics and SCM context. Despite realizing the impact Blockchain might have on their industry, companies seem hesitant to dedicate resources to look into possible Blockchain applications. Apart from that, the findings also provide insights into the perspectives of different participant groups. Taking the hierarchical level of the participants into account, our data suggests middle managers are much less enthusiastic about Blockchain than c-level executives or operational employees. They give significantly lower ratings on Blockchain benefit and adoption likeliness for the use cases, see fewer beneficiaries, and expect more showstoppers. For example, 60% of the middle managers raise concerns about data security, while only 28% of c-level executives share this reservation. An explanation for this lack of enthusiasm might lie in the better overview middle managers have of their processes. Since they are likely responsible for implementing new IT solutions (at least from the business perspective), they might feel Blockchain is overhyped and is just another IT development praised as the silver bullet.

Our data suggests significant differences between logisticians (working for logistics service providers, manufacturers, and retailers), on one hand, and consultants and scientists on the other. These differences are striking in terms of beneficiaries and adoption barriers. Logisticians have difficulties getting a clear idea of the benefits and use cases, while consultants and scientists worry about the technological maturity of Blockchain. Our results underline the importance of carving out possible use cases for logistics and supply chain management. If people from a rather conservative industry, like logistics, are expected to buy into new technology, the benefit must be very clear. Just because something is new doesn't mean logisticians get too excited.

A third differentiator is the level of Blockchain experiences. Our data suggests the more experienced participants are (e.g., exploring use cases instead of just observing the development in the industry), the more positive they evaluate Blockchain. We find steadily growing ratings of benefit and adoption likeliness across the four experience levels shown in Figure 4. Also, more experienced participants identify more beneficiaries. Their perspective on possible barriers shifts: While only one fourth of the little-experienced participants expect collaborating with different partners to be a showstopper, around 60% of participants having implementation experiences indicate a high level of collaboration and commitment might be a barrier. Our findings show small-scale experiments with Blockchain applications are vital to understand the barriers and benefits of Blockchain. Logisticians should engage in experiments to find out if and how Blockchain could be of use for their own company.

6 Conclusion

In this paper, we presented a study on the current state of Blockchain in logistics and SCM. To shed light on the first research question pertaining to possible applications of Blockchain in logistics and SCM, we introduced four use case exemplars that are under exploration in theory and practice. To provide insights into the second research question about Blockchain being a trick or a treat for logistics and SCM, we presented the findings of a survey. The survey was conducted in the logistics and SCM industry and investigated the participants' opinion on use cases, showstoppers, and benefits of Blockchain. As our findings show, Blockchain is expected to have a considerable impact on the logistics industry and should be considered a treat. However, our findings also show logisticians should start "chewing" on Blockchain soon. They are well-advised to find out how much of the overall Blockchain hype could be developed into a value-add for their service portfolio before someone else does.

References

Abeyratne, S. A. and R. P. Monfared (2016). "Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger". In: *International Journal of Research in Engineering and Technology* 5.9, pp. 1–10.

Allison, I. (2017). *Maersk and IBM Want 10 Million Shipping Containers on the Global Supply Blockchain by Year-End*.

Apte, S. and N. Petrovsky (2016). "Will Blockchain Technology Revolutionize Excipient Supply Chain Management?" In: *Journal of Excipients and Food Chemicals* 7.3, pp. 76–78.

Casey, M. J. and P. Wong (2017). *Global Supply Chains Are About to Get Better, Thanks to Blockchain*.

Christidis, K. and M. Devetsikiotis (2016). "Blockchains and Smart Contracts for the Internet of Things". In: *IEEE Access* 4, pp. 2292–2303.

Chu, Y., J. Ream, and D. Schatsky (2016). *CFO Insights: Getting Smart About Smart Contracts*. Deloitte.

DeCovny, S. (2017). *Experts Discuss Tackling Pharma Supply Chain Issues With Blockchain*.

Dickson, B. (2016). *Blockchain Has the Potential to Revolutionize the Supply Chain*.

Eastwood, G. (2017). *Why Blockchain is the Future of IoT*.

Gartner (2015). *Gartner Says 6.4 Billion Connected "Things" Will Be in Use in 2016, Up 30 Percent From 2015*. Tech. rep.

Groenfeldt, T. (2017). *IBM And Maersk Apply Blockchain To Container Shipping*.

Hackett, R. (2016). *Walmart and IBM Are Partnering to Put Chinese Pork on a Blockchain*.

Hackett, R. (2017). *Wal-Mart Explores Blockchain for Delivery Drones*.

Hair, J. F., W. C. Black, B. J. Babin, and R. E. Anderson (2009). *Multivariate Data Analysis*. Upper Saddle River: Prentice Hall.

Kersten, W., M. Seiter, B. von See, N. Hackius, and T. Maurer (2017). *Trends and Strategies in Logistics and Supply Chain Management – Digital Transformation Opportunities*. Hamburg: DVV Media Group.

Lomas, N. (2015). *Everledger Is Using Blockchain To Combat Fraud, Starting With Diamonds*.

Mackey, T. K. and G. Nayyar (2017). "A Review of Existing and Emerging Digital Technologies to Combat the Global Trade in Fake Medicines". In: *Expert Opinion on Drug Safety* 16.5, pp. 587–602.

Meade, A. W. and S. B. Craig (2012). "Identifying Careless Responses in Survey Data". In: *Psychological Methods* 17.3, pp. 437–455.

Morabito, V. (2017). *Business Innovation Through Blockchain*. Cham: Springer International Publishing.

O'Marah, K. (2017). *Blockchain For Supply Chain: Enormous Potential Down The Road*.

Petersen, M., N. Hackius, and W. Kersten (2016). "Blockchains für Produktion und Logistik: Grundlagen, Potenziale und Anwendungsfälle". In: *Zeitschrift für wirtschaftlichen Fabrikbetrieb* 111.10, pp. 626–629.

Pilkington, M. (2016). "Blockchain Technology: Principles and Applications". In: *Research Handbook on Digital Transformations*. Ed. by F. X. Olleros and M. Zhegu. Edward Elgar Publishing, pp. 1–39.

Popper, N. and S. Lohr (2017). *Blockchain: A Better Way to Track Pork Chops, Bonds, Bad Peanut Butter?*

Shaffer, E. (2017). *Walmart, IBM Provide Blockchain Update*.

Sutherland, W. J., P. Barnard, S. Broad, M. Clout, B. Connor, I. M. Côté, L. V. Dicks, H. Doran, A. C. Entwistle, E. Fleishman, M. Fox, K. J. Gaston, D. W. Gibbons, Z. Jiang, B. Keim, F. A. Lickorish, P. Markillie, K. A. Monk, J. W. Pearce-Higgins, L. S. Peck, J. Pretty, M. D. Spalding, F. H. Tonneijck, B. C. Wintle, and N. Ockendon (2017). "A 2017 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity". In: *Trends in Ecology and Evolution* 32.1, pp. 31–40.

Tapscott, D. and A. Tapscott (2016). *Blockchain Revolution*. 1st ed. New York: Penguin Random House.

Tian, F. (2016). "An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology". In: *2016 13th International Conference on Service Systems and Service Management (ICSSSM)*, pp. 1–6.

Underwood, S. (2016). "Blockchain Beyond Bitcoin". In: *Communications of the ACM* 59.11, pp. 15–17.

Xu, J. J. (2016). "Are Blockchains Immune to All Malicious Attacks?" In: *Financial Innovation* 2.25, pp. 1–9.

Yli-Huumo, J., D. Ko, S. Choi, S. Park, and K. Smolander (2016). "Where Is Current Research on Blockchain Technology? - A Systematic Review". In: *PLoS ONE* 11.10, pp. 1–27.

Zhao, J. L., S. Fan, and J. Yan (2016). "Overview of Business Innovations and Research Opportunities in Blockchain and Introduction to the Special Issue". In: *Financial Innovation* 2.28, pp. 1–7.

Zheng, Z., S. Xie, H.-N. Dai, and H. Wang (2017). "Blockchain Challenges and Opportunities: A Survey". In: *International Journal of Electric and Hybrid Vehicles*, pp. 1–23.

A Peer-To-Peer Platform for Decentralized Logistics

Olivier Gallay[1], Kari Korpela[2], Niemi Tapio[1], Jukka K. Nurminen[3]

1 – University of Lausanne

2 – Lappeenranta University of Technology

3 – VTT Technical Research Centre of Finland

We introduce a novel platform for decentralized logistics, the aim of which is to magnify and accelerate the impact offered by the integration of the most recent advances in Information and Communication Technologies (ICTs) to multi-modal freight operations. The essence of our peer-to-peer (P2P) framework distributes the management of the logistics operations to the multiple actors according to their available computational resources. As a result, this new approach prevents the dominant players from capturing the market, ensures equal opportunities for different size actors, and avoids vendor lock-in. The latest ICTs such as Industrial Data Space (IDS), Blockchain, and Internet-of-Things (IoT) are used as basic building blocks which, together, enable the creation of a trusted and integrated platform to manage logistics operations in a fully decentralized way. While IDS technology allows for secured data exchange between the different parties in the logistics chain, Blockchain technology handles transaction history and agreements between parties in a decentralized way. IoT enables the gathering of real-time data over the logistics network, which can be securely exchanged between the different parties and used for managing the decision-making related to the control of the freight transportation activities. The practicability and the potential of the proposed platform is demonstrated with two use cases, involving various actors in the logistics chains.

Keywords: Peer-to-Peer Logistics; Blockchain; Industrial Data Space; Internet-of-Things

1 Introduction

Digitized logistics integration, beside drastically decreasing manual work, opens the door for novel ways of optimizing the logistics processes and transport routes. It also enables real-time monitoring of transportation flows in order to react dynamically to unexpected circumstances. As a result, the integration of the newest Information and Communication Technologies (ICT) offers great potential to improve cost-effectiveness in logistics and enables new business models based on real-time economics. Today, 70% of companies lack operational performance data along the entire value chain, (World Economic Forum, 2016). To face this issue within the European Union (EU), the long-term goals and the related roadmaps of the European Technology Platform ALICE (c.f. etp-logistics.eu) aim at a 10%–30% increase of efficiency in the EU logistics sector, which means EUR 100–300 billion cost relief for the European industry. A true "people, planet and profit" oriented logistics and supply chain sector contributes not only in industry competitiveness but also in meeting environmental policy targets.

One of the main challenges in logistics is that various independent parties are involved (freight forwarders, 3rd party logistic service providers, multimodal transport operators, carriers, etc.). Communication between these parties needs to be accurate, and the associated necessity is to create a common platform where all parties share the necessary relevant information. Several attempts towards the implementation of such a platform were carried out in several past EU-funded research projects (such as CONTAIN, FREIGHTWISE, e-FREIGHT, or iCargo, c.f. containproject.com, freightwise.tec-hh.net, eutravelproject.eu), and recently by commercial products such as Uber Freight. The problem when adopting such approaches is that some organization needs to run the common platform. While having platform dominance often represents a good business opportunity for the company running the platform, other actors have to pay fees and follow the whims of the platform owner. Furthermore, a single gatekeeper poses a risk for diversity and fairness in the market. Multiple competing platform companies, on the other hand, create the risk of a splintered market resulting into non-optimal logistics decisions in separate silos.

An alternative solution – and the focus of this contribution – is to handle logistics management in a peer-to-peer (P2P) fashion. While P2P logistics is sometimes understood as crowd-sourced transportation, we concentrate here on the conventional transportation industry. The essence of our P2P approach is that the logistics management system is fully distributed to the computational resources of the actors. The outcome is a distributed system with a network of interactions between parties. The proposed framework aims at using and integrating two recent P2P technologies: Industrial Data Space (IDS), developed at Fraunhofer Institute in Germany, and Blockchain, which was initially a key part of cryptocurrencies (Mukhopadhyay et al., 2016), but is now a separate technology on its own.

The proposed P2P approach blocks dominant players from capturing the market, ensures equal opportunities for different size actors, and avoids vendor lock-in. The essence of the introduced P2P platform is that the cloud-enabled transport management system is distributed over multiple actors according to their computational capabilities. The result is a distributed system with a network of interactions between actors and entities, which enables smart and innovative data based services.

Ultimately, we present a framework that goes beyond the paradigm of a centralized platform, and we propose a fully P2P architecture for logistics management. The platform combines three novel technologies: IDS, Blockchain, and IoT. All these technologies have been tested and used in their specific fields but never been combined in the present way. Therefore, the proposed system provides the logistics field with a totally new management approach, and open possibilities for new innovations and businesses utilizing this platform.

2 Related Work

The key question raised in this paper is how can a logistics management system based on P2P ideas help and provide new value in the digitized supply chain, and solve the contradiction between interoperability and data sovereignty. While the technical components we are introducing in the present contribution have already been investigated in various contexts including logistics, they have never been applied in an integrated fashion to logistics as an enabler for smart and innovative data based services. Some companies are already marketing P2P logistics services (e.g. p2plogistics.co.uk), however it is important to note that they are simply using a centralized client-server architecture platform to match the transport needs and crowd-sourced providers. Ideas towards a P2P approach have first been envisioned on a general level in a Hewlett-Packard patent (Chen and Hsu, 2007), but application of such ideas to logistics has not been systematically studied nor experimented so far.

A recent survey by Sternberg and Andersson (2014) gives an exhaustive overview of the existing scientific research contributions on distributed freight management. In particular, the authors observe that "decentralized intelligence in logistics can be viewed as a disruptive architectural innovation operating on an IT-infrastructure level, displaying massive network effects that has not yet materialized". Sternberg and Andersson see the problem of reaching the critical mass of adopters as a key challenge, and highlight the importance of industrial experiments.

Industrial Data Space (IDS) reference architecture and technology have been created by the Fraunhofer Institute and the Industrial Data Space Association (c.f. industrialdataspace.org). The association has currently 50+ members ranging from manufacturing, production, logistics, ICT to services, such as DB Schenker, ThyssenKrupp, Schaeffler, FESTO, Bosch, SICK, Salzgitter and SMEs like Setlog and Quinscape. Experiments on IDS technology are ongoing in 10+ European IDS hubs. The IDS Connector software component (Otto, 2017), which allows for secured data sharing and processing, is currently standardized in a fast track procedure by DIN, the leading German standardization institution, and by ISO in parallel. IDS is recognized as a key enabler for future industry platforms by the EU's Digitising European Industry initiative (European Commission, 2016; Jarke, 2017; Jesse, 2017).

Yuan et al. (2016) claim in a recent contribution that Blockchain can revolutionize intelligent transport systems, and as a result the use of Blockchain in various industrial and logistics applications is currently widely investigated. Blockchain has already been applied to logistics in several R&D projects and academic research. For instance, Apte and Petrovsky (2016) discuss the implementation of Blockchain within pharmaceutical supply chains, and Zhang et al. (2017) combine Internet-of-Things (IoT) and Blockchain in order to propose a novel business model for IoT services. Tian (2016) combines RFID and Blockchain for building a traceable agri-food supply chain. A recent contribution by Korpela, Hallikas, and Dahlberg (2017) studies the challenges raised by the integration of Blockchain in supply chain frameworks. Blockchain design functionalities are shown to support good integration for ledger and smart contracting, however for a global integration within a supply chain context, a common standardized data model is additionally required to secure the interoperability, which is performed by the IDS technology in the platform proposed in this contribution. Blockchain technology and various associated industrial business cases are currently analyzed in a national project in Finland (BOND - Blockchains bOosting FiNnish InDustry, c.f. vtt.fi/sites/BOND). A Scandinavian consortium (DBE Core, c.f. dbecore.com/portfolio/what-next), including IBM, is working on the integration of Blockchain open logistics APIs, as well as on associated new business models for open transportation ecosystems. SmartLog (c.f. kinno.fi/en/smartlog), a EU-funded research project, is currently investigating the first Proof-of-Concept implementation for a solution involving Blockchain and IoT in the logistics industry.

The business opportunities raised by the appearance of IoT have been acknowledged by Gartner to represent a major market prospect in the next decade (Rivera, 2014). Papert and Pflaum (2017) give recommendations on how IoT could be implemented by logistics companies. One of their key findings is that the IoT platform should be based on open interfaces and open source software to support communication among different applications. There exist several recent studies on various ways to apply IoT to logistics, transportation, and vehicles (Da Xu, He, and Li, 2014; Guerrero-Ibanez, Zeadally, and Contreras-Castillo, 2015; Guo et al., 2017; Contreras, Zeadally, and Guerrero-Ibanez, 2017).

In terms of Technology Readiness Level (TRL), the Blockchain technology is already in massive use in digital currencies, but for other use cases it is still under development (TRL5). IDS Connector technology is used in industrial pilots (TRL5). Positioning and other IoT sensing technologies have been in production use for a long time (TRL9). The integration of IDS, Blockchain, and IoT has not been fully demonstrated in industrial use (TRL5) for logistics system management.

3 A smart platform for decentralized value chain operations

3.1 Concept

The ultimate objective of this contribution is to take advantage of novel P2P technologies, in order to enable the creation of a trusted, decentralized logistics platform. Figure 1 gives a general sketch of the proposed platform. IDS technology allows for data exchange between the different actors in the logistics chain. Its key feature is data governance, in the sense that it enables parties to work together without releasing confidential information to each other. IDS Connectors can implement in a decentralized fashion any type of taylored algorithms, e.g. for calculating transportation options matching the customers' needs, or for merging procurement systems. Since these algorithms are embedded inside

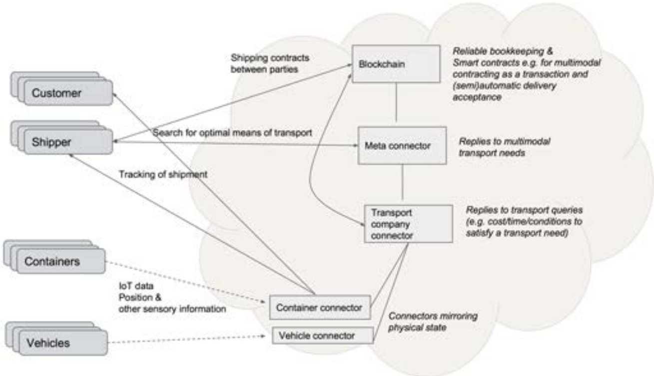

Figure 1: High-level system architecture with example data flows.

IDS Connectors, proprietary business logic does not need to be disclosed. In a similar way, the customer company can work privately with the IDS Connector using sensitive data without disclosing it to anyone. Trust is further enhanced by the option to have IDS Connectors certified by 3rd parties.

Like IDS, Blockchain technology works in a P2P fashion, managing transaction history and verifying agreements between parties in a decentralized way. The distributed trust, which Blockchain enables, is a perfect match to the distributed IDS technology. Indeed, Blockchain technology allows for the establishment of Smart Contracts, which, once agreed, can be run by autonomous programs without any human intervention.

IoT is the third key building block needed in order to allow timely information in a dynamic environment (Al-Fuqaha et al., 2015). This consists in a large collection of networked sensors or other devices communicating with each other and delivering data to higher level applications using a suitable middleware (Razzaque et al., 2016). The data collected by IoT sensors can be stored, processed, and shared by applying cloud-computing (Botta et al., 2016).

In Figure 1, IDS Connectors represent containers (or other transport units), vehicles, and transport companies. The meta-connector is a virtual entity searching, optimizing, and managing end-to-end transport routes and processes, which can span multiple means of transportation and multiple transport companies. A brokering service maintains a directory of available IDS Connectors. IDS allows for standardization of the data transfers and the data formats used. As a result, IDS provides all actors of the logistics chain with an easy access to the platform, and to the services it offers. IDS Connectors communicate with each other, and with the IDS broker. For instance, when a company needs a transport service, it uses a dedicated meta-connector, which performs route optimization by combining the best transport means and service providers to form a single transport chain.

The transport unit IDS Connector also collects and manages information from IoT sensors installed in the containers or in other transport units. The essential events in IoT data, such as crossing national borders or sensory readings of changed freight conditions (e.g. location, temperature, humidity level, etc.), can also be stored into the Blockchain. In this way, e.g. automatic payment can be authorized after the transport unit has been delivered to the final customer and the merchandises in it have been stored in agreed conditions (e.g. temperature). The transport unit IDS Connector can also offer real-time information on the location and other sensor data to the company that ordered the transport service.

Let us now focus on one of the most natural process to be handled, where optimal transport routes have to be negotiated. Thanks to the present P2P platform, a multi-modal routing algorithm can be implemented within the IDS Connectors in order to determine the best transportation means and schedule for each freight request arising in the logistics system. In addition to monetary objectives, the algorithms could use, e.g. environmental factors as an optimization goal. Since any user can create new IDS Connectors, adding new specific routing algorithms is possible, depending on the customers' needs. The route planning of the transport units might typically consist of:

— An offline algorithm, which first determines an ideal multi-modal routing schedule, based on the data available at the time of the transportation request.

— The initial schedule may thereafter be modified and adapted via the execution of an online algorithm, which determines dynamic recourse actions in case of perturbations to the original schedule (delays, disruptions).

For the latter online algorithm above, there are many events which have an impact on the time of arrival of a transport unit: traffic perturbations, rest periods of the driver, as well as breakdowns. For these reasons, IoT is implemented in order to constantly track freight units and vehicles along their journey. Real-time data is collected from the numerous IoT sensors deployed over the logistics network as well as from the freight units and vehicles measured via GPS-tracking. Open data, including real-time traffic information, can also be considered by the online routing module. The estimated time of arrival can be automatically calculated with the help of GPS coordinates that are sent automatically to the IDS Connector. Time consuming events can also be manually sent (e.g. in the GS1 EDI XML format) to the customer via the IDS platform, which will re-optimize the route and recalculate the estimated time of arrival. The driver himself can negotiate new time slots through a smartphone-based platform. Hence, the online algorithm is able to help in bringing more reliability to the logistics network and allows for a substantial reduction of transportation times. When it comes to multi-modal transportation networks, it allows to react to random perturbations during the shipment by dynamically and automatically managing mode changes using the IDS Connectors, and to manage the related contracting with the involved carriers by using the Blockchain feature. Through the IDS technology, the routing module can provide users emitting a freight request not only with the best option (in terms of transportation costs, route, and combination of modes), but also with possible routing alternatives and associated costs. This allows the users to autonomously plan on the online platform their freight request based on their particular needs.

Blockchain technology is used to confirm and store contracts negotiated by IDS Connectors. Also, transactions associated with the routing decision-making processes, which involve the selection of various transport carriers and operators, are recorded by the IDS platform on the Blockchain to ensure future traceability, visibility, and transparency. As Smart Contracts are shared programs inside Blockchains, they do not need any 3rd party validators, and can be executed automatically, when all definitions in the contract have been fulfilled, e.g. when IoT readings satisfy agreed conditions.

Such a decentralized logistics platform will have to be first implemented in smaller use cases, as the ones presented in Section 4 below. This will allow hence to investigate in parallel the role and potential of new service and product innovations by identifying service gaps. This is done by analyzing how companies and the business ecosystem increase revenues and cut costs by using real-time business processes, and identifying opportunities for cost-cutting through the elimination of manual work.

3.2 Impact

The essence of the present decentralized P2P platform is to show the potential for high interoperability through distributed Blockchain and IDS technologies. In the following, we discuss the benefits of the proposed platform, grouped by the enabling technologies.

Peer-To-Peer

The proposed platform, based on P2P technologies, allows for a flexible integration of ICT and operational processes of the different involved parties. It offers a complete real-time mapping between physical freight and digital information flows. Applying P2P technologies and cloud-based service architecture ensures easy access to the system with user devices ranging from sensor platforms, mobile phones/tablets, and PC computers. The P2P concept provides hence the different supply chain partners with equal opportunities, no matter their size and importance. Another key benefit of the P2P approach is scalability, as the workload is divided, and there is hence no bottleneck in the system.

IDS and Data Sharing

The data sovereignty of IDS technology has been designed in order to enable data exchange while keeping control of the data. Horizontal collaboration is implemented via the effective information and data exchange that is achieved through the IDS Connector technology. As only the IDS Connector APIs are fixed, new ICT players can start introducing new functionalities by creating their own IDS Connectors. The system is therefore open to both logistics and ICT parties to easily join in. The APIs enable the integration of IDS Connectors to company internal data systems, and thus to their specific operational processes. IDS Connectors ensure data privacy and confidentiality of sensitive business data.

Blockchain

Blockchain technology provides the different supply chain partners with the technical basis for trust while the data governance mechanisms of IDS will handle information sharing. As a result, Blockchain technology is used to build a reliable general electronic bookkeeping solution, as the Blockchain approach is highly successful in guaranteeing the truthfulness of the data.

Internet-Of-Things

IoT technologies are used to monitor the location and state of freight units and vehicles. As a result, real-time data, such as location and other IoT sensor data, can be used in managing the logistics decision-making, which is directly used to control the freight transportation activities. In this way, taylored real-time optimization algorithms can be implemented in order to allow for reacting dynamically to deviations. Ease of deployment is a key design goal for IoT data collection mechanisms.

Multi-Modal Routing Algorithms

The proposed platform allows for the development of novel static and dynamic algorithms for optimal multi-modal transport decisions. Indeed, the above ICT technologies facilitate the data and information sharing between the different parties, and hence using them opens the door for smarter decision-making. More efficient logistics will focus on shortening transportation routes, increasing vehicle load factor, reducing empty runs by improved route planning, as well as shortening the lead time and consequently reducing inventories. This will result in creating savings in transportation costs. The resulting financial savings arise as a result of both better combinations of loads and higher load factors, and better selections among multiple routes and the specific advantages offered by the different transportation modes (flexibility of trucks, smaller environmental footprint of railways, lower costs of maritime transport, etc.), which helps to shorten the freight delivery routes, as well as to reduce CO2 emissions. All these aspects will hence also have a positive impact on the ecological footprint of the logistics system.

As highlighted in (Korpela, Hallikas, and Dahlberg, 2017), a combined stack of standardized technologies is a major enabler for the accelerated development of a many to many integration model. In general, the architecture of Blockchain technology (design elements and functionalities) is commonly shared, and such standardization has facilitated its integrated use over the Internet. IoT integration is implemented in our platform with the use of standardized IDS Connectors.

4 Towards implementation and acceptance

Two initial use cases, which emphasize the different aspects of the proposed concept, have been identified with various industrial partners. While each of these two use cases requires some specific implementation work, they both share the key technology platform introduced in this contribution. The concrete aim of such initial uses cases is to highlight at a smaller-scale, and hence at a reduced investment risk, how the logistics platform based on IDS and Blockchain technologies is able to improve the efficiency of logistics operations.

4.1 Secure tracking of deliveries

This use case originates from a company that delivers turnkey solutions for industrial machine and facility builders. The customer base runs 14'000 turbines for power generation, 700 paper machines and about 1 million power transmission systems in 70 different countries. Hundred sites are handling the delivery of these customized solutions to the customers, using dozens of different transport companies. Besides the shipment of heavy machinery parts, which have to travel thousands of kilometers cross-borders, a solution includes thousands of other vital components that are needed to complete the delivery. Collecting information during the in-transit phase is vital to be able to better predict the time of arrival of the components, and help planning to ensure on-time delivery with reduced lead-time.

This use case possesses all the facets needed to study how to facilitate on-demand based operations in a globally distributed project context, and how new technologies related to P2P, talking containers (IoT), and dynamic routing can lower the costs while improving performance in logistics related to large projects. In particular:

— Routing: on-time delivery, real-time estimation of time of arrival, and negotiation of a suitable delivery time. Both the shipper and the customer can better organize their delivery processes and avoid congestion on delivery platforms. Thanks to improved real-time routing information enabled by the gathering of real-time IoT data and IDS-based routing algorithms (from the carrier to the logistics service provider and the customer), the installation site can prepare its processes for on-time or late delivery. In case of perturbations, real-time re-routing allows to minimize the lateness.

— Tracking: all parcels and containers are able to communicate their location and condition measured through different IoT sensors that are linked with the package and the components themselves.

— Security: all information throughout the delivery process is stored in a secured Blockchain for multiple purposes. During the delivery phase, the location and transportation circumstances of the containers are to be recorded and stored securely. Once assembled, the operational history can be stored in the same Blockchain to cover the whole lifecycle including the recycling procedure at the end of lifetime.

— Integration: existing transport management systems and mobile apps can be integrated in order to ensure the ability of the logistics platform to work together with legacy solutions and with standardized formats.

4.2 Blockchain and data integration for forest industry logistics

The Digital Business Ecosystem Consortium (DBE Core) drives the implementation and adoption of logistics API integration to Blockchain and Smart Contracts for end-to-end digital information exchange. The members of the DBE Core consist of industry companies in two large business domains: the bio-refinery process and the maritime ship building industry. They form a customer base for logistics services in land operations across Finland, as well as cross-border operations to global markets. The DBE Core companies are operating over 100 countries.

As a case example in Finland, the Lappeenranta region has one of the largest forest industry clusters in the world. Every day more than 1000 full truckloads of raw material is received in three regional bio-refinery industry locations, and some 300 truckloads per day are delivered to European customers. A new truck is unloaded every 3 minutes. The import from Russia (which crosses EU borders) is over 15 million cubic meters of wood. The distributed stocks in the forest are geo-located, and hundreds of Small and Medium Enterprises (SME) logistics companies handle their transportation on a daily basis.

Logistics operations in different industry locations, supplier locations, warehouses, ports and railroads require a well-conducted and interoperable logistics management system. Logistics companies are generally using intermediate operators to transfer and map the data between organizations and their systems. Currently, lots of manual work is required to integrate the information, which generates high costs. Therefore SME suppliers are exposed to be replaced by Tier-2 or Tier-3 suppliers.

All stakeholders of DBE Core have decided jointly to move towards a common logistic integration based on open Application Programming Interfaces (APIs). The development is based on global business process standards (OASIS/UBL).

The development and piloting of Blockchain integration and Smart Contracting can be established by the following steps: *(a)* defining DBE Core consortium Blockchain (e.g. with IBM Bluemix and HyperLedger), *(b)* Logistic API integration to Blockchain, *(c)* Smart Contract integration to control and automate transactions, and *(d)* secure interoperability with IDS Connectors.

The P2P platform described in this paper will support the knowledge creation and sharing of concepts and tools to reach the DBE Core visions and goals in the following ways:

— Real-time visibility to logistics transportation: monitoring and control of logistics processes enables the development of demand supply forecasting algorithms based on pull model for delivery control, in order to reduce lead-time, waiting times, and manual work.

— Securing the data storing and sharing by Blockchain on B2B and IoT transactions.

— Automating the supply and logistics integrations in gross organizational environment.

5 Conclusions and future work

We present a fully decentralized platform for logistics management based on IDS and Blockchain technologies which, combined with the gathering of real-time IoT data, enables to address efficiently the challenges raised in the logistics networks nowadays. The proposed P2P framework allows for supporting interoperability between different actors in the logistic chains, sharing securely the data between the different parties, and using it for optimal planning based on IoT data.

The platform allows for an implementation that is not affected by scalability issues, and that is not limited by geographical borders. In particular, facilitation of cross-border transportation is one of the main issues that the platform facilitates. By lowering the threshold for new actors to join in, it is expected that new opportunities will arise both in dynamic transportation optimization, and in 3rd party development of new components and services to the platform.

Interestingly, the overall concept discussed in this paper also has applicability beyond logistics systems. There are a number of areas which share similar key characteristics: *(i)* cooperation and data transfer between multiple independent parties is essential, *(ii)* splitting the market into separate silos run by different companies reduces the benefits, and *(iii)* a dominant platform company can have an unhealthy role in controlling the market. Examples of such services include auction sites, travel rental booking sites, and most importantly social media sites. In these contexts, we typically observe strong network effects where the value of the network rises with the number of participants it is able to attract. As a consequence, the dominant player has a major advantage and is able to push the smaller players away from the market, resulting into monopolistic positions (for an overview see e.g. Haucap and Heimeshoff, 2014). While the shared economy helps smaller players to enter the market to perform the actual work (Einav, Farronato, and Levin, 2016), the competition at the more lucrative management layer tends to fade. Being able to provide the similar service in a P2P fashion represents a way to gain the benefits of network effects without facing the problems of dominant, monopolistic parties. For instance, Munsing, Mather, and Moura (2017) have explored Blockchain technology in connection with electricity networks to eliminate the need of a microgrid operator.

It is important to note that towards the implementation of the proposed platform, business model implications will have to be investigated in parallel, in order to unveil the associated new innovation opportunities and ecosystem effects, as well as the additional needs for development, standardization, and other activities, which are necessary to bring the enhanced logistics solutions into operational use.

References

Apte, S. and N. Petrovsky (2016). “Will blockchain technology revolutionize excipient supply chain management?” In: *Journal of Excipients and Food Chemicals* 7.3, pp. 76–78.

Botta, A., W. De Donato, V. Persico, and A. Pescapé (2016). "Integration of cloud computing and internet of things: A survey". In: *Future Generation Computer Systems* 56, pp. 684–700.

Chen, Q. and M. Hsu (2007). *Peer-to-peer inter-enterprise collaborative process management method and system*. US Patent US 09/823,581.

Contreras, J., S. Zeadally, and J. A. Guerrero-Ibanez (2017). "Internet of vehicles: Architecture, protocols, and security". In: *IEEE Internet of Things Journal*.

Da Xu, L., W. He, and S. Li (2014). "Internet of things in industries: A survey". In: *IEEE Transactions on Industrial Informatics* 10.4, pp. 2233–2243.

Einav, L., C. Farronato, and J. Levin (2016). "Peer-to-peer markets". In: *Annual Review of Economics* 8, pp. 615–635.

European Commission (2016). "Digitising european industry: Reaping the full benefits of a digital single market". In:

Al-Fuqaha, A., M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash (2015). "Internet of things: A survey on enabling technologies, protocols, and applications". In: *IEEE Communications Surveys & Tutorials* 17.4, pp. 2347–2376.

Guerrero-Ibanez, J. A., S. Zeadally, and J. Contreras-Castillo (2015). "Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies". In: *IEEE Wireless Communications* 22.6, pp. 122–128.

Guo, L., M. Dong, K. Ota, Q. Li, T. Ye, J. Wu, and J. Li (2017). "A secure mechanism for big data collection in large scale internet of vehicle". In: *IEEE Internet of Things Journal* 4.2, pp. 601–610.

Haucap, J. and U. Heimeshoff (2014). "Google, Facebook, Amazon, eBay: Is the Internet driving competition or market monopolization?" In: *International Economics and Economic Policy* 11.1, pp. 49–61.

Jarke, M. (2017). "Data spaces: Combining goal-driven and data-driven approaches in community decision and negotiation support". In: *International Conference on Group Decision and Negotiation*. Springer, pp. 3–14.

Jesse, N. (2017). "The future of innovation with third party data". In: https://www.talend.com/blog/2017/07/18/building-data-sharehouse-agile-data-management-industrial-data-space-ids.

Korpela, K., J. Hallikas, and T. Dahlberg (2017). "Digital supply chain transformation toward blockchain integration". In: *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Mukhopadhyay, U., A. Skjellum, O. Hambolu, J. Oakley, L. Yu, and R. Brooks (2016). "A brief survey of cryptocurrency systems". In: *14th Annual Conference on Privacy, Security and Trust (PST), 2016*. IEEE, pp. 745–752.

Munsing, E., J. Mather, and S. Moura (2017). "Blockchains for decentralized optimization of energy resources in microgrid networks". In:

Otto, B. (2017). "Reference architecture model for the industrial data space". In: http://industrialdataspace.org/en/publications/industrial-data-space-reference-architecture-model-2017.

Papert, M. and A. Pflaum (2017). "Development of an ecosystem model for the realization of Internet-of-Things (IoT) services in supply chain management". In: *Electronic Markets* 27.2, pp. 175–189.

Razzaque, M. A., M. Milojevic-Jevric, A. Palade, and S. Clarke (2016). "Middleware for internet of things: A survey". In: *IEEE Internet of Things Journal* 3.1, pp. 70–95.

Rivera, J. (2014). "Gartner says the internet of things will transform the data center". In: http://www.gartner.com/newsroom/id/2684616.

Sternberg, H. and M. Andersson (2014). "Decentralized intelligence in freight transport: A critical review". In: *Computers in Industry* 65.2, pp. 306–313.

Tian, F. (2016). "An agri-food supply chain traceability system for China based on RFID & blockchain technology". In: *13th International Conference on Service Systems and Service Management (ICSSSM), 2016*. IEEE, pp. 1–6.

World Economic Forum (2016). *Digital Transformation of Industries: Logistics Industry*. Tech. rep.

Yuan, Y. and F.-Y. Wang (2016). "Towards blockchain-based intelligent transportation systems". In: *IEEE 19th International Conference onIntelligent Transportation Systems (ITSC), 2016*. IEEE, pp. 2663–2668.

Zhang, Y. and J. Wen (2017). "The IoT electric business model: Using blockchain technology for the internet of things". In: *Peer-to-Peer Networking and Applications* 10.4, pp. 983–994.

IoT-coordinated Logistics in Product-Service Systems

Jürgen Anke[1]

1 – Hochschule für Telekommunikation Leipzig

Product-Service Systems (PSS) enable new value to customers compared to traditional selling of goods, e.g. through new business models such as Performance-based contracting (PBC) and Pay-per-use (PPU). This turns the manufacturer into a service provider, which has to perform maintenance, repair and operation (MRO) tasks for the products provided in a PSS. Therefore, the service provider must organize the logistics of the equipment, spare parts, and consumables in a timely manner. In this paper, we evaluate the impact of Internet of Things (IoT) technology for the support of logistics-related tasks in PSS. More specifically, the required tasks with relevance of logistics are identified using case studies and existing literature. For each task, we derive trigger events and how they can be discovered automatically. Based on this, we propose a generalized architecture for IoT-enabled logistics processes in PSS, which can be used to better understand the operation of such systems and support their design.

Keywords: product-service systems; cyber-physical systems; Internet of Things; Performance-based contracting

1 Introduction

The proliferation of Internet of Things (IoT) technologies and ongoing servitization efforts in manufacturing companies break ground for new business models, such as pay-per-use (Weinberger, Bilgeri and Fleisch, 2016). One of the most frequently cited example for this principle is the “power-by-the-hour” concept of Rolls-Royce for aircraft engines (Neely, 2008). The concept of combining goods and services into an integrated offer is called Product-Service System (PSS). In more elaborate usage-based or results-based PSS, the task of managing and operating equipment is shifted from the user to provider (Elmazoski, et al., 2016). While this reduces the risk, required knowledge and maintenance resources at the customer, it causes uncertainty about the overall cost as it is usage-dependent. For the provider, which takes over the responsibility for maintaining the equipment, this model offers continuous revenue through long-time contracts, customer lock in and other benefits (Lockett et al., 2011).

The main aspect of PSS in regard to logistics is that products are not being sold but instead provided as a service or as part of service (Cavalieri and Pezzotta, 2012). Therefore, the provider strives to keep the contracted equipment running for two reasons: First, the revenue depends on the usage, and second, any penalty payments due to service level agreement (SLA) violations have to be avoided. To increase usage fees and prevent penalty payments for SLA violations with PBC, the service provider aims to perform all required activities to maintain high availability at the lowest possible cost. The employment of IoT-technology for products in PSS offers large efficiency potentials in their operation. For example, spare parts, consumables, and technicians need to be provided in timely manner to fulfill the agreed upon SLAs. Consequently, the physical processes should be coordinated efficiently through the IoT-enabled products in PSS. The major challenge is to employ IT in a way that provides high availability for the user and efficient servicing for the provider at the same time. However, the link between the concept of PSS and underlying technology for it has just recently emerged in literature (Ardolino et al., 2017; Sala et al., 2017).

In this paper, the role of information technology for the coordination of logistics processes for PSS is investigated. Using several case studies as well as existing literature, we identify information demand and data sources required for the logistics tasks as part of the overall equipment servicing. Based on that, a generalized architecture for a cyber-physical system (CPS) is proposed, which integrates information flows required to coordinate material flows for products equipped with IoT-technology. From a technology perspective, IoT-data and events from the product are processed with analytics in the cloud to trigger the execution of business processes in the transaction systems at the service provider.

Our results are to help practitioners to design and manage PSS based on CPS. They could also serve as a basis for services fourth-party logistics providers (4PLs), which can then be contracted as part of the overall PBC-PSS service system by the service provider. As a theoretical contribution, we aim to improve the conceptual basis for smart service systems at the intersection of service science, cyber-physical systems, logistics and big data (Demirkan et al., 2015; Medina-Borja, 2015).

2 Conceptual Foundation

The key concepts of this research are product-service systems, business models, IoT and cyber-physical systems, which are briefly introduced in this section.

The combination of tangible physical goods and intangible services into an integrated offer is called a product-service system (PSS) (Mont, 2002; Baines, et al., 2007). PSS take a marketing oriented perspective as they describe what companies offer and what value customers can gain from these offers. According to a popular classification proposed by Tukker (2004), PSS can be subdivided into product-oriented, use-oriented and result-oriented PSS. The first category involves the selling of product and the offer of accompanying services. Use-oriented services still focus on the product but the product remains in the ownership of the provider and it is billed on a per use basis. In result-oriented PSS, the consumer and the provider agree on a defined result without the involvement of any pre-determined product (Tukker, 2004). A trend contributing to the emergence of PSS is the so-called “servitization”, which refers to the transformation of product-oriented offers into services (Neely, 2007).

In contrast to the selling of goods, PSS allow for business models, in which the product remains property of the service provider, while the user pays for the actual service. Typical variants are pay-per-use and performance-based contracting. In pay-per-use (PPU) models, the user is charged for the metered usage of a good, e.g. by the hour as in car sharing services like Car2Go (Gassmann, Frankenberger and Csik, 2014). Performance-based contracting (PBC) refers to the “the contractual approach of tying at least a portion of supplier payment to performance" (Selviaridis and Wynstra, 2014). In their survey of 241 papers on PBC, Selviaridis and Wynstra (2014) recognize "performance specification and evaluation, payment scheme design and its impact on supplier behavior and, to a lesser extent, risk allocation and attitudes" as the main aspects in PBC research. A comprehensive review of PBC from a business perspective is provided by Essig et al. (2016).

The integration of Internet of Things technology into physical products has been identified as basis for innovative business models (Allmendinger and Lombreglia, 2005; Herterich, Uebernickel and Brenner, 2015). This particularly holds true for PBC and PPU a, which are both identified as business models benefitting from IoT, especially from the "Remote Usage and Condition Monitoring" component in the "digitally charged products" pattern (Fleisch, Weinberger and Wortmann, 2015). The "IoT-enabling" of products constitutes of them being equipped with sensors, embedded computation and communication capabilities to turn them into smart products (Porter and Heppelmann, 2014; Valencia et al., 2015; Barbosa et al., 2016). The remote access to the product status, operation conditions etc. for monitoring and control provide the basis for data-driven product-related services (Herterich, Brenner and Uebernickel, 2016; Kagermann, Riemensperger and Weckesser, 2016). To support the servicing of PSS, it is therefore key to integrate IoT devices and the events they generate with business processes, which has emerged as topic in the recent years, e.g. by Schief et al. (2011) and Meyer, Ruppen and Magerkurth (2013).

The theoretical foundation for these systems are Cyber-physical systems (CPS), denoting the integration of computing with physical processes, which can affect each other (Lee, 2008). In a more comprehensive understanding, CPS are socio-technical systems, consisting of sensors, actuators, embedded systems, digital networks, Internet services as well as coordination and management processes (Broy, Cengarle and Geisberger, 2012). CPS can be considered as the technical implementation of a PSS with smart, connected products (Sala et al., 2017).

In summary, within this research, we assume that all PBC and PPU business models for technical products create a PSS. Furthermore, we consider CPS as the conceptual basis for the implementation of such PSS with IoT-enabled technical products, as CPS integrate physical goods, processes, people and information technology into a holistic system.

3 Research Goal and Methodology

The research goal of this paper is to identify how logistics processes in PSS can be coordinated through IoT-enabled products. For that, the following methodology is applied: Based on existing literature and several real-world cases, main logistics tasks are identified. These tasks are consolidated into a framework, which relates information demands, data sources and analytics to these logistics tasks. From this, a generalized CPS architecture is derived to describe the coordination of logistics processes in IoT-enabled PSS.

It is important to note that there is a variety of options to configure PSS offerings (Freund and Stölzle, 2016). As Essig et al. (2016) point out, PBC is related to both industrial marketing and operations and service management (OSM). For our research, we focus on the OSM part and PSS with the following characteristics:

— The product part of the PSS is a technical product

— The PSS is offered in a pay-per-use or performance-based contracting model

— Maintenance, Repair and Operations (MRO) are at least partly contained in the offer

4 Related work

While the conceptual foundation addresses the basic concepts of this research, the related work section presents recent work at the intersection between PSS, CPS and PBC/PPU business models.

The potentials and challenges of the application of performance-based contracting in manufacturing are surveyed by Holmbom, Bergquist and Vanhatalo (2014). They find that there is a lack of empirical evidence on the improved profitability for both the provider and the user, although this is one of the key motivators the implementation of PBC. The procurement of performance in a PSS from a buyer's perspective is discussed by Elmazoski et al. (2016). They establish a framework which links payment models and service orientation to identify different PSS purchasing options for the buyer. Specifically, it discusses the incentives for buyer and provider in the various models (Elmazoski, et al., 2016).

A number existing contributions deal with the planning and configuration of supply networks for services or PSS, e.g. by Lockett et al. (2011) and Xu et al. (2016). However, they do not address the operational benefits of IoT for improved information management for servitized products. Johnson and Mena (2008) propose and integrated model for product supply chains and service supply chains in order to cater of servitized products. Furthermore, they highlight the importance of real-time information and the information flow management. Grubic (2014) discusses the importance of real-time information as a measure to mitigate risk in servitization, without relating to CPS. The value-based organization of business processes for a product-service supply chain is described by He et al. (2016).

Several existing contributions deal with various aspects of IT-supported logistics process coordination of smart products. Examples are the dispatching of technicians (Bader et al., 2017), the replenishment process (Alfathi, Lyhyaoui and Sedqui, 2015), spare parts availability (Chaudhuri and Ivcekno, 2017), replenishment policy (Hosoda and Disney, 2012). The potentials of CPS for maintenance, repair and operations (MRO) have been analyzed by Trentesaux et al. (2015) using two case studies of aircrafts and trains. They, however, do not provide a link to business models and focus on MRO tasks in general rather than PSS logistics in general. Still, the contribution of Trentesaux et al. is a helpful work to illustrate the principle of applying CPS to support maintenance in product fleets. Ardolino et al. (2017) present a very recent and comprehensive study on the application of digital technologies such as IoT, Cloud Computing and Predictive Analytics in servitization. Furthermore they introduce helpful terminology for service transformation paths such as “availability provider” (offering products in a PPU model) and “performance-provider” (offering products in a PBC model), both of which employ IoT for usage data, product performance.

With regard to related work, it can be concluded that the IoT-enabling of PSS to support new business models has been widely discussed from various perspectives in literature. However, to the best of our knowledge, we could not identify a contribution regarding the logistics of PSS and their coordination with the help of IoT-enabled information flows.

5 Case Analysis

We use publicly available information as well as scientific publications on the following cases of existing real-world IoT-enabled PSS to identify logistics requirements:

— Winterhalter provides industrial dishwashers in a "pay-per-wash" business model. The fixed price includes all detergents, water treatment, baskets, maintenance and service. There is also no minimum contract duration, which means that all the installed equipment may have to be transferred to another customer soon after the signup (Winterhalter, 2016).

— Canon offers document management solutions in pay-per-page contracts, which include consumables replenishment, spare parts, maintenance and technician labor (Canon Europe, 2017). Canon equipment can connect and send to the Canon eMaintenance platform data related to meters and machine status, ink levels, activity log and fault registry (Ardolino et al., 2017).

— Kaeser Compressors offer is called Sigma Air Utility, which uses a PBC business model with a fixed price per cubic meter compressed air. Users get an individual solution concept, which is build, operated and optimized by Kaeser. To enable remote monitoring of all compressors, the Sigma Telecare is employed to gather data for both predictive maintenance and energy efficient operation. Spare parts are delivered through a worldwide network of logistics partners. These measures are aimed to reduce downtimes and unnecessary onsite visits (Kaeser Kompressoren, 2017).

— Car2Go is a car sharing system, which is offered in various large cities, e.g. Berlin, Vienna, Vancouver and New York City. Users are billed by the minute, with prices depending on the type of car. Cars can be located, booked and opened via a smartphone app. Car2Go will take care of all required maintenance and cleaning, as well as paying for parking lots, insurance and other vehicle related cost. If a car has to be refueled by the user, he or she gets a credit of 10 extra driving minutes (car2go Deutschland GmbH, 2017).

— Hewlett Packard offers the “Instant Ink” program for toner cartridges, which are charged in a cost-per-page model. Different plans with various numbers of included pages for a monthly subscription are offered for occasional, moderate and frequent users. To participate, the user must own an Instant Ink compatible HP printer, and register for the “HP connected” service, which is facilitates the transmission of usage information from the user to HP over the internet. The user receives new toner cartridges automatically via postal mail before the ink runs out. Also, empty cartridges are returned to HP partners for recycling via postage-paid shipping material (HP Development Company, 2017).

From these cases, we can derive the following main logistics processes: Delivery, Maintenance, Replenishment and Recycling (see table 1). As Delivery is a process that takes place before the actual operational logistics support begins, we do not further discuss it in this research. However, it is obviously a process that is part of the provider’s fleet management and can be also supported using IoT data.

Table 1: Logistic requirements of the selected cases

Case	Model	Delivery	Maintenance	Replenish-ment	Recycling
Winter-halter	PPU (per Wash)	Machine included	Included	Detergents	(unclear)
Canon	PPU (per Page)	Setup by Canon	Labor, spare parts, mainte-nance kits, print heads	Ink	
Kaeser Com-pressors	PBC (per m^3 com-pressed air)	By Kaeser, incl. setup	Labor, spare parts	n/a	n/a
Car2Go	PPU (per Minute)	Pickup by User	Cleaning, maintenance	Refueling by User	n/a
HP Instant Ink	PPU (per Page)	Parcel	n/a	Ink	Empty cartridges

6 A Framework for PSS Logistics

In this section, the results from the case analysis and related work are consolidated into a general framework for PSS logistics. The main focus is the identification of provision of information that is required to allow for a timely conduct of logistics processes. First, we propose the following terms to generalize the logistics of a PSS:

- Equipment: a product, machine or device that performs the desired service
- User: the entity that requires the performance of an equipment
- Provider: the company that provides the PSS and takes care of its servicing
- Service Level Agreement (SLA): an agreement between user and provider on quantifiable properties of a service, e.g. availability.
- Consumables: any physical goods, which are used up by the equipment during operation, such as ink in a printer, lubricants in machines etc.
- Spare Part: any component, which has to be replaced during the use of the equipment
- Replenishment: any physical operation that is required to provide the equipment with consumables.
- Maintenance: any physical operation that is required to improve the reliability and longevity of equipment, which can also be determined through safety laws and regulations, e.g. calibration of measurement devices. Examples for maintenance are cleaning, inspection, and replacement of wearing parts.
- Repair: any physical operation that is required to restore the correct function of an equipment
- Recycling: the return of any unwanted physical material that is created during the operation of the equipment.

To conduct the identified processes as efficiently as possible, IoT-enabling is employed to create a CPS which provides automation for the individual steps from physically identifiable demand, digitally detected demand, data transmission, event processing, workflow initiation, physical provisioning of material, delivery to operation site, and local operations to fulfill the demand.

For each of the operational logistics processes, the following characteristics are thus required to propose a generalized CPS architecture: To perform the process, one or multiple workflows have to be performed at the service provider. This creates a demand for information, which helps to decide, when these workflows have to be triggered. To fulfill these demands, data on usage, condition, location etc. is needed from the equipment. This data is then processed using analytics, which mainly fall in the category of predictive analytics or machine learning algorithms (Ardolino et al., 2017). The consolidated characteristics for PSS logistics process support are shown in Table 2.

Table 2: Generalized support PSS logistic processes

Process	Workflows	Information Demand	Data Sources	Analytics
Replenish-ment	Schedule service, schedule transport, allocate consuma-bles	Reach of remaining consumables	Stock levels, operational data	Consumption patterns
Repair	Schedule service, allocate spare parts	Remaining lifetime of components	Equipment sensors, operational data	Predictive Maintenance
Main-tenance	Schedule service	Maintenance demand	Operational hours, inspec-tion history	Determine maintenance timeframe
Recycling	Schedule transport	Pickup demand	Current level of residuals	Determine pickup timeframe

On this basis, we can deduct a generalized architecture of a CPS to support PSS logistics. It is based on the framework for Cyber-physical Logistics System (CPLS), as proposed by (Prasse, Nettstraeter and Hompel, 2014). It also relates to the findings of Grubic (2014) with regard to the usage of real-time information and remote monitoring in servitization. The concept of cloud-based analytics for predictive maintenance has been previously described, e.g. by Johanson and Karlsson (2016).

The main elements of the proposed architecture are:

1. The equipment, which contains sensors, embedded computing and communication capabilities to record and transmit required data, such as operational status, location, fill levels etc.
2. The data is sent to an IoT Cloud, where it is stored in a database. All analytics functions can be performed using this data. Based on the outcome of the analytics functions, trigger events are created.
3. The providers' transaction systems in the backend receive the events and can initiate workflows accordingly.
4. The logistics execution within the triggered workflows can be conducted with the help of technicians for local operations and logistics service providers for delivering spare parts and consumables as well as picking up any residuals for recycling.

The proposed architecture is presented in figure 1.

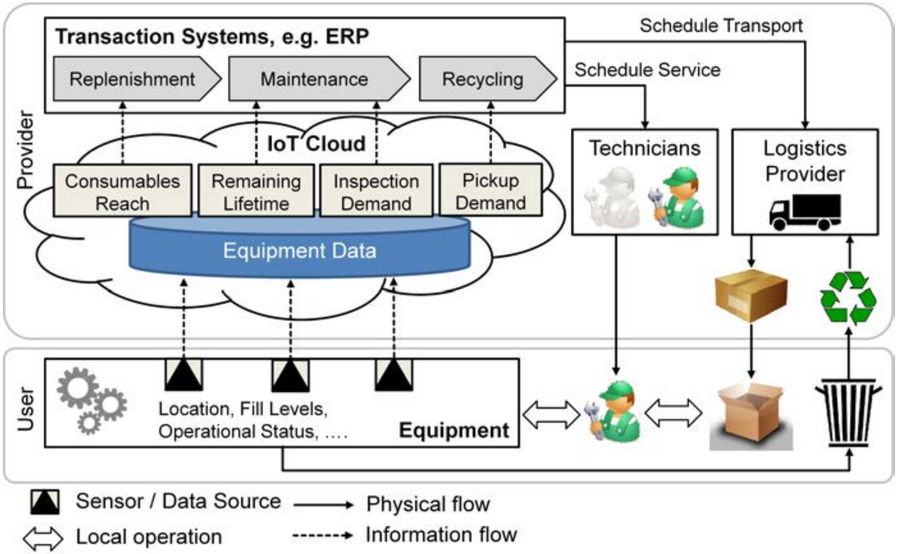

Figure 1: A generic CPS architecture to support PSS logistics

7 Discussion

This research shows that there is currently a lack of generalized knowledge on the principles and mechanisms of logistics for PSS. Given the high complexity of PSS implemented on CPS, such knowledge is required to describe, explain, and design these systems.

The results of this paper are meant to be a first step towards these goals. We found that a common basis for PSS logistics can be established, even though the analyzed cases show a wide spectrum of designs. Specifically, the processes of replenishment, maintenance, and recycling could be identified to be of relevance. Besides, a set of terms have been proposed to describe the main actors and relations.

Furthermore, the employment of IoT technology to monitor equipment either avoids error-prone and expensive manual data entry or makes the overall PSS offer economically viable in the first place. The proposed generalized architecture is a conceptual model of a CPS for PSS logistics, which shows how equipment, IoT-technology, analytics, and workflows can be combined to coordinate logistics processes for PSS. SLAs in performance-based contracted products create special requirements on the logistics process, which must be considered as part of the integrated product-service system (PSS). The use of IoT technology in physical equipment enables efficient information flow to support the fulfillment of SLAs.

Practitioners and researcher alike may use our results to get a better overall understanding of PSS logistics. For the design of equipment targeted for use in a PSS, it is advisable to consider the information demand and related data to prepare for the integration of sensors, computation and communication capabilities. It might also help logistic service providers to develop new services for PSS providers.

It should be noted, that in this research, only a relatively small number of cases was analyzed. Furthermore, all case data was gained through existing public information, mainly from the providers themselves. A larger sample of cases and additional expert interviews with providers and users will probably create a more detailed and differentiated result. However, we are convinced that the main findings of this research still hold true, and can serve as a framework for further research results.

For future research, we identified the three different directions fleet management, SLA compliance and refinement for implementation:

1. Fleet management: Within this paper, only the operational logistics of a PSS are covered. From a provider's perspective, the provisioning and operation of PSS is a fleet management task, which also includes logistics processes. Examples are the provisioning to and the return of the equipment from the customer to the provider. For these processes, the current location and status is also important, e.g. to decide whether outstanding requests can be already fulfilled with a particular equipment in the fleet. Besides the actual transport, technicians might be required to dismount and setup the equipment at the respective locations. Other fleet management tasks include the use of monitoring data for optimized operations, e.g. to reduce wear of components and energy consumption.
2. SLA compliance: While it has already been stated that SLAs can be part of the PSS operation, the adherence to these SLAs was not in scope of this research. For that, a timing perspective has to be established in the proposed framework. Another improvement could be the inclusion of additional data from the user, e.g. production schedules, shift plans etc. which can be used as additional input in the scheduling to reduce interruptions. Likewise, the process status, e.g. tracking and tracing information could be relayed back to the equipment in order to optimize its operations and provide more detailed information on the current status to the user. Along these lines are proactive business processes, which are triggered based on forecasts rather than actual events. This might be of particular value in planning and dispatching processes, e.g. to optimize management of product fleets, scheduling of technicians as well as the optimization of stock levels and order sizes for replenishment.
3. Refinement for implementation: As the proposed architecture is on a conceptual level, it needs further refinement with regard to both information logistics and infrastructure. Information logistics should describe in detail, which data has to be recorded, how it is pre-processed, when it has to be transmitted, where it is stored, how it is analyzed, and how long it has to be retained to fulfill the requirements of the PSS. Infrastructure refers to a concrete technical system with concrete sensors, communication technology, transmission protocols and IoT cloud architectures.

8 Conclusion and Outlook

The increasing importance of PSS is recognized both in academia and practice. With the emergence of reliable IoT-technology, the integration of physical and digital processes in CPS becomes a driver for further automation and thus efficiency in the operation in such systems. When technical products are offered in PBC or PPU business models, the product is combined with operational services into a PSS. Such PSS were successfully established in practice, as shown by the cases mentioned earlier. With that, the buyer of the PSS transfers the responsibility and risk for these operations to the service provider, e.g. the manufacturer of the product. While such scenarios can create a variety of positive effects for both user and provider, we focused the effects of IoT-functionality in technical products on the efficient logistics operations for PSS.

The results of this research fulfill the goal of identifying how logistics processes in PSS can be coordinated through IoT-enabled products. More specifically, the research links existing concepts from different research fields together, such as PSS, CPS, IoT, PBC and PPU business models and relates them to real-world use cases. With these results, we aim to contribute to the digitization of logistics with regard to the operation of PSS. However, we acknowledge that this can only be a starting point, as there are many open research issues, some of which were presented in the previous section.

To follow these research directions is worthwhile from our point of view. Not only because of the increasing relevance of PSS in general. Also the ongoing digitization provides new opportunities to improve efficiency and customer value of such systems. Various technological advancements within the broader concept of “Industrie 4.0” can have an enormous impact on the operation of PSS. For example, additive manufacturing (commonly known as “3D printing”) might allow producing spare parts when they are needed nearby the place of operation, which reduces stock keeping and delivery times. Another relevant are of innovations is human-computer interaction. For example, augmented reality might help less experienced local technicians to get context-based instructions for repair or maintenance. Their interaction might be enriched with information from senior engineers at the manufacturer, who are able to see both the view of the technician as well as the current state of the product and its history. In summary, such developments may reduce lead times in case of failures and improve efficiency in the operations, but increase complexity of the overall system. Therefore, the design and operation of PSS in PBC or PPU business models requires an integrated approach of technical, commercial and behavioral aspects.

References

Alfathi, N., A. Lyhyaoui, and A. Sedqui (2015). “A New Product Driven System Concept for the Replenishment Process”. In: *Operational excellence in logistics and supply chains*. Ed. by W. Kersten, T. Blecker, and C. M. Ringle. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin and Berlin: epubli GmbH.

Allmendinger, G. and R. Lombreglia (2005). “Four strategies for the age of smart services”. In: *Harvard Business Review* 83.10, p. 131.

Ardolino, M., M. Rapaccini, N. Saccani, P. Gaiardelli, G. Crespi, and C. Ruggeri (2017). “The role of digital technologies for the service transformation of industrial companies”. In: *International Journal of Production Research* 83.10, pp. 1–17.

Bader, S., M. Vössing, C. Wolff, J. Walk, and M. Maleshkova (2017). “Supporting the Dispatching Process for Maintenance Technicians in Industry 4.0”. In: *Tagungsband der 9. Konferenz Professionelles Wissensmanagement*. Ed. by S.-V. York, S. Zander, and A. Harth.

Baines, T. S., H. W. Lightfoot, S. Evans, A. Neely, R. Greenough, J. Peppard, R. Roy, E. Shehab, A. Braganza, A. Tiwari, J. R. Alcock, J. P. Angus, M. Bastl, A. Cousens, P. Irving, M. Johnson, J. Kingston, H. Lockett, V. Martinez, P. Michele, D. Tranfield, I. M. Walton, and H. Wilson (2007). “State-of-the-art in product-service systems”. In: *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 221.10, pp. 1543–1552.

Barbosa, J., P. Leitão, D. Trentesaux, and S. Karnouskos (2016). “Cross Benefits from Cyber-Physical Systems and Intelligent Products for Future Smart Industries”. In: *Proceedings of the 14th IEEE International Conference on Industrial Informatics*.

Broy, M., M. V. Cengarle, and E. Geisberger (2012). “Cyber-Physical Systems: Imminent Challenges”. In: *Large-scale complex IT systems*. Ed. by R. Calinescu and D. Garlan. Vol. 7539. LNCS sublibrary. SL 2, Programming and software engineering. Heidelberg and New York: Springer, pp. 1–28.

Canon Europe (2017). *Total Service Care Large Format Solutions*.

car2go Deutschland GmbH (2017). *car2go Carsharing*.

Cavalieri, S. and G. Pezzotta (2012). “Product–Service Systems Engineering: State of the art and research challenges”. In: *Product Service System Engineering: From Theory to Industrial Applications Product Service System Engineering: From Theory to Industrial Applications* 63.4, pp. 278–288.

Chaudhuri, A. and J. Ivcekno (2017). “Framework for improving spare parts availability using big data analytics: case study of a mining equipment manufacturer”. In: *9th Service Operations Management Forum*.

Demirkan, H., C. Bess, J. Spohrer, A. Rayes, D. Allen, and Y. Moghaddam (2015). “Innovations with Smart Service Systems: Analytics, Big Data, Cognitive Assistance, and the Internet of Everything”. In: *Communications of the Association for Information Systems* 37.35.

Elmazoski, J., A. H. Glas, U. David, M. Eßig, and M. Seiter (2016). “Performance-based contracting of PSS: Methodological aspects of an experimental investigation”. In: *Proceedings of the 25th IPSERA Conference*.

Essig, M., A. H. Glas, K. Selviaridis, and J. K. Roehrich (2016). “Performance-based contracting in business markets”. In: *Industrial Marketing Management* 59, pp. 5–11.

Fleisch, E., M. Weinberger, and F. Wortmann (2015). “Business Models and the Internet of Things”. In: *Interoperability and Open-Source solutions for the Internet of Things*. Ed. by I. Podnar Žarko, K. Pripužić, and M. Serrano. Vol. 9001. LNCS. Cham: Springer, pp. 6–10.

Freund, S. and W. Stölzle (2016). “Configuring PBC for operating of capital goods – A case-based typology”. In: *Supply Management Research: Aktuelle Forschungsergebnisse 2015*. Ed. by R. Bogaschewsky, M. Eßig, R. Lasch, and W. Stölzle. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 177–200.

Gassmann, O., K. Frankenberger, and M. Csik (2014). *The business model navigator: 55 models that will revolutionise your business ; [discover the 55 business models responsible for 90% of the world’s most successful companies]*. 1. publ. Always learning. Harlow u.a.: Financial Times Pearson Education.

Grubic, T. (2014). “Servitization and remote monitoring technology”. In: *Journal of Manufacturing Technology Management* 25.1, pp. 100–124.

He, T., W. Ho, Y. Zhang, and P. K. Dey (2016). “Organising the business processes of a product servitised supply chain: A value perspective”. In: *Production Planning & Control* 27.5, pp. 378–393.

Herterich, M. M., W. Brenner, and F. Uebernickel (2016). “Stepwise Evolution of Capabilities for Harnessing Digital Data Streams in Data-Driven Industrial Services”. In: *MIS Quarterly Executive* 15.4, pp. 297–318.

Herterich, M., F. Uebernickel, and W. Brenner (2015). “The Impact of Cyber-physical Systems on Industrial Services in Manufacturing”. In: *Procedia CIRP* 30, pp. 323–328.

Holmbom, M., B. Bergquist, and E. Vanhatalo (2014). “Performance-based logistics – an illusive panacea or a concept for the future?” In: *Journal of Manufacturing Technology Management* 25.7, pp. 958–979.

Hosoda, T. and S. M. Disney (2012). “On the replenishment policy when the market demand information is lagged”. In: *International Journal of Production Economics* 135.1, pp. 458–467.

HP Development Company, L. P. (2017). *HP Instant Ink*.

Johanson, M. and L. Karlsson (2016). “Service architectures for product and production availability: A system of systems approach”. In: *11th System of Systems Engineering Conference (SoSE), IEEE*. Piscataway, New Jersey: IEEE, pp. 1–6.

Johnson, M. and C. Mena (2008). “Supply chain management for servitised products: A multi-industry case study”. In: *International Journal of Production Economics* 114.1, pp. 27–39.

Kaeser Kompressoren (2017). *Operator model: SIGMA AIR UTILITY*.

Kagermann, H., F. Riemensperger, and P. Weckesser (2016). *Smart Service Welt: Digitale Serviceplattformen – Praxiserfahrungen aus der Industrie: Best Practices*. Ed. by acatec. München.

Lockett, H., M. Johnson, S. Evans, and M. Bastl (2011). “Product Service Systems and supply network relationships: An exploratory case study”. In: *Journal of Manufacturing Technology Management* 22.3, pp. 293–313.

Medina-Borja, A. (2015). “Editorial Column—Smart Things as Service Providers: A Call for Convergence of Disciplines to Build a Research Agenda for the Service Systems of the Future”. In: *Service Science* 7.1, pp. ii–v.

Mont, O. (2002). “Clarifying the concept of product–service system”. In: *Journal of Cleaner Production* 10.3, pp. 237–245.

Neely, A. (2007). “The Servitization of Manufacturing: An Analysis of Global Trends”. In:

Neely, A. (2008). “Exploring the financial consequences of the servitization of manufacturing”. In: *Operations Management Research* 1.2, pp. 103–118.

Porter, M. E. and J. E. Heppelmann (2014). “How Smart, Connected Products Are Transforming Competition”. In: *Harvard Business Review*.

Prasse, C., A. Nettstraeter, and M. ten Hompel (2014). “How IoT will change the design and operation of logistics systems”. In: *2014 International Conference on the Internet of Things (IOT)*. Piscataway, NJ: IEEE, pp. 55–60.

Sala, R., V. Zanetti, G. Pezzotta, and S. Cavalieri (2017). “The role of technology in designing and delivering Product-service Systems”. In: *International Conference on Engineering, Technology and Innovation (ICE/ITMC)*.

Schief, M., C. Kuhn, P. Rösch, and T. Stoitsev (2011). “Enabling Business Process Integration of IoT-Events to the Benefit of Sustainable Logistics”. In: *1st International Conference on Logistics, Informatics and Service Science (LISS 2011)*.

Selviaridis, K. and F. Wynstra (2014). “Performance-based contracting: A literature review and future research directions”. In: *International Journal of Production Research* 53.12, pp. 3505–3540.

Trentesaux, D., T. Knothe, G. Branger, and K. Fischer (2015). “Planning and Control of Maintenance, Repair and Overhaul Operations of a Fleet of Complex Transportation Systems: A Cyber-Physical System Approach”. In: *Service orientation in holonic and multi-agent manufacturing*. Ed. by T. Borangiu. Vol. 594. Studies in Computational Intelligence. Cham: Springer, pp. 175–186.

Tukker, A. (2004). “Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet”. In: *Business Strategy and the Environment* 13.4, pp. 246–260.

Valencia, A., R. Mugge, J. Schoormans, and H. Schifferstein (2015). “The Design of Smart Product-Service Systems (PSSs): An Exploration of Design Characteristics”. In: *International Journal of Design* 9.1, pp. 13–28.

Weinberger, M., D. Bilgeri, and E. Fleisch (2016). “IoT business models in an industrial context”. In: *at - Automatisierungstechnik* 64.9.

Winterhalter (2016). *Pay-Per-Wash*.

Xu, Z., X. G. Ming, T. Wu, and M. Zheng (2016). “Product Service Supply-Chain Design”. In: *Handbook of manufacturing engineering and technology*. Ed. by A. Y. C. Nee. Springer reference. New York [New York] and Boston, Massachusetts: Springer and Credo Reference, pp. 3219–3237.

Towards a Web Based Transportation Infrastructure

Florian Kleedorfer[1], Christian Huemer [2]

1 – Research Studios Austria

2 – Technical University of Vienna

The level of digitalization within transport companies is much higher than the level of digitalization across organization boundaries. This fact suggests that there is room for improvement. However, this situation is not likely to change as long as there is no financial incentive for the whole sector to cooperate in establishing a shared communication infrastructure. In this paper, we present our approach for building such an infrastructure using the method of design science. The goal is an open, Web based, de-centralized network operated by transport organizations themselves. Based on expert interviews, we argue that the current situation causes frictions that our approach may help reduce, thereby providing the incentive to participate. The proposed system is described in terms of its existing technologicial base, the Web of Needs, and the extensions needed to provide the required functionality, giving an overview of the current state of implementation.

Keywords: linked data; transport; decentralization; digitalization

1 Introduction

Companies in the transportation domain have developed their IT infrastructure in recent years, giving clients ever easier access to the services they provide. Mobile apps and Websites allow users to create accounts and comfortably book transports, make pick-up/delivery appointments, and pay their invoices. These developments reduce the transaction cost of becoming and onboarding a new client.

However, this style of digitalization is not without drawbacks. For one, there are considerable costs associated with building and maintaining these tools. Because of that, they are primarily designed to meet the requirements of the transporter, not its clients. They tend to lock users in a streamlined one-stop shop for transportation, whereas the opposite would be in the clients' interest: to be able to compare service offerings and prices across vendors, and to switch between vendors easily. Instead, clients are confronted with a plethora of communication channels, apps and on-line accounts each of which lets them communicate with just one vendor.

Recent economic successes of *matchmaking platforms* like Uber or Airbnb (*Uber* 2017; *Airbnb* 2017) have proved the need for a vendor-independent medium where supply and demand can meet. Such a medium for the management of transactions between market participants obviously serves as a unifying force leading to standardized interfaces between the participants, lowering the cost of finding a partner and enabling trust between newfound partners.

While a remedy to some issues of the more traditional style of digitalization, this approach has drawbacks, too. Most prominently, matchmaking platforms tend to create winner-take-all (or winner-take-most) situations: For any given product or service, it makes more sense for a participant to join the platform that already hosts more of the clients the participant interested in. The result is a small number of dominant platforms that have a de-facto monopoly.

The intrinsic logic of the platform business model is to allow transactions only within the platform, and to allow only the transactions that are directly or indirectly economically profitable for the platform. While the platform model thus allows participants to reach a bigger pool of potential partners than the traditional model (each participant operates their own infrastructure), it introduces new limits on that pool out of the platform's self-interest: only members of the platform are meant to interact.

Our goal is the development of a de-centralized, open, standards-based infrastructure for transportation, providing the adequate technology for all market participants without the limitations induced by the necessary self-interest of the centralized platform model. The vision is to interconnect the existing IT systems of transport companies on a protocol level instead of connecting each of them to one central hub. This approach allows for diverse, inter-operable software products that can be tailored to each participant's needs; all market participants can operate services of their own and thereby retain ownership of their data and they are free to engage in interactions with any other participant that implements the protocol.

In this paper, we report findings from expert interviews that support the relevance of the problem we are addressing and give us a direction for further development. We explain how we harness prior work and show which adaptations and extensions have to be made in order to solve the problem, and finally, we describe the current state of design and implementation.

2 Research Method

In our work, we follow the method of design science in information systems research, proposed by Hevner (Hevner et al., 2004). According to this framework, design science is primarily focused on the creation of technological artifacts. The research topics are obtained from the environment of the artifact in the form of relevant business needs. When finished, artifacts have to be applied in the environment in order to assess their effects. This cyclic process is called the *relevance cycle*. Using the available knowledge base, artifacts are iteratively adapted and evaluated using rigorous scientific methods. Theoretical insights are added to the knowledge base through scientific publication, completing the *rigor cycle* (Hevner, 2007).

In the following, we describe our research process as an application of this method. The first step is the assessment of problem relevance and the elicitation of business needs, which we do by interviewing domain experts. As a second step we propose a design for technological artifacts to address the business needs we found.

3 Relevance: Qualitative Interviews

The problem we postulate is that there is considerable friction between market participants in the domain of transportation in its current state of digitalization. Our main hypothesis is that a unified open infrastructure that allows for matching suitable business partners with each other can reduce friction.

3.1 Sample Selection and Data Collection

In order to asses the problem relevance and to find out which frictions are deemed important by domain experts, we conducted qualitative expert interviews with individuals who are active in the field of transportation (DiCicco-Bloom and Crabtree, 2006). The interview partners were initially identified by Web search for keywords mainly from the domain of courier and parcel services in Austria. Interviews were conducted with those who showed interest in cooperating. The range then was extended by a snowball technique (Varvasovszky and Brugha, 2000). In the course of this analysis, the focus was widened to include the forwarding sector as initial results pointed toward greater than expected problem relevance in that area. A number of interviews were conducted at an agricultural trade fair, which explains the influence of that sector in the results.

In total, 27 interviews were conducted with a prepared interview plan that evolved a little over time; five interviews could be completed according to the plan, the others had to be shortened due to limited availability of the participants. The interview partners are active in the roles of trader(10), transporter(5), logistics(2), broker(2), or others (8). Data collection was done by note-taking. The notes were subsequently analyzed for commonalities that caught our interest.

3.2 Findings

In the following we highlight our findings, noting the number of participants whose interviews support each one. For each finding, we argue how it influences our assessment of problem relevance. While some findings will directly relate to functionality currently under development, some findings can at this point only serve as motivations for functionality that may be provided by our infrastructure in the future.

1. **Trust.** Especially when freight is high-volume or high-value, established contacts between consignor and transporter are highly valued. Trusting new players is difficult and not deemed necessary once good business relationships have been set up. This finding disconfirms the relevance of our work because players prefer existing business relationships and do not need matching with new partners. On the other hand, it would motivate a feature that enables trust in new partners, and of one that allows representing and leveraging one's business network. Support: 9.

2. **Digitalized communication.** Transportation is digitalized only within companies, and even within companies, the actual execution is often not digitalized (communication with driver or for confirming handovers). If it is digitalized across companies (other than via e-mail or messaging apps), it is set up in such a way that the client company integrates the API or uses the user interface of the transport company. The general view of market participants was that the main means of communication is through phone calls, using E-mail for written confirmation. Companies do have systems using barcodes, matrix codes or electronic identification tokens to trace their consignments, but they do not seem to work across companies. This finding supports problem relevance because it shows there is room for automation of communication across companies. Support: 4.

3. **Documents.** In some constellations, consignors and consignees demand the original paper documents from the consignor be passed on to the consignee, incurring additional complexity. One such docucment is the CMR[1] consignment note (UNECE, 1956) that needs to be signed by the consignee and find its way back to the consignor - failing to obtain the signed CMR consignment note can incur considerable costs. The consignee, on the other hand, has little to no incentive to send it back, which can cause serious problems.[2] Together with Finding 2 (digitalized communication), this finding is a strong argument for further technological harmonization of standards for transport documents and their seamless integration in everyday business. Support: 4.

[1] CMR is short for the United Nations' *Convention on the Contract for the International Carriage of Goods by Road*

[2] Overall, delivery paperwork is being replaced by electronic data interchange. Concerning the CMR document it should be noted that at the time of this writing, the digital e-CMR Waybill is available in a number of European countries. (UNECE, 2008). It was not mentioned in any of our interviews, though.

4. **Privacy.** Keeping trade secrects is an important issue for players in the transportation domain. Several experts voiced concerns that their contracts and bids may be inspected by other parties in an open system, and therefore took quite a reserved stance toward our work. Multiple experts stated that if requests for quotes and their bids could be revealed to a selected audience only, it would be a system they would welcome. Support: 4.
5. **Appointments.** Depending on the means of transportation and the situation of the consignee, the complexity of making appointments for pick-up and delivery as well as the consequences of errors can vary greatly. The main medium for making appointments and informing about changes is telephone. Large logistics companies have dedicated communication channels (apps or automated SMS). This finding generally supports the relevance of our work if the developed technology supports the integration of processes and resources for coordinating appointments so as to standardize the situation, removing the burden of last-minute improvisation and providing a reliable record of the events that led to a problem. Support: 3.
6. **Calls.** Being able to talk to their counterpart in addition to written communication is described as important by some experts. It allows for quick problem solving, helps building trust quickly (video calls or meetings in person even more so), and it is a good way of maintaining the customer relationship. Ideally, it would be possible to reach the relevant person (e.g. call the truck driver to inform them of an important change). This finding provides support for an integration of voice or video chat in a technology managing transport relationships. One broker noted that a conference call with multiple participants would be ideal. Support: 3.
7. **Certificates.** Some experts stated that friction is caused by having to prove that all parties in the logistics chain hold a certain certificate, such as the GMP+ certificate for sustainable production. This finding supports problem relevance and may warrant the use of blockchains. Support: 3.
8. **Framework agreements.** High-frequency consignors do not set up each transport assignment individually. Rather, they select transportation partners, often on a yearly basis, set up a framework contract, and then execute many transports with easily calculated rates and quick planning. This finding seems to disconfirm the problem relevance as a system that matches transportation partners for each individual transport is not

needed for this situation. However, if the solution allows for finding transportation partners for framework agreements, and setting up individual transports based on a framework agreement, possibly in a private call for proposals among partners with whom a framework contract has been set up, the described situation might even be improved. Support: 3.

9. **Return freight.** For a one-off transport, getting a transportation quote can take a long time (one week is not uncommon for agricultural goods) because of the need to find a freight for the return journey. This finding supports problem relevance as the delay causes friction in the information or negotiation phase that might be reduced by a more efficient process of finding a transport request for the return journey. A solution feature that could be especially useful here would be the option to offer a transport only on the condition that a corresponding return contract is found, and to represent and monitor the condition satisfaction automatically. Support: 3.

10. **Price sensitivity.** Multiple experts stated that transportation is very price-sensitive - price is the main decision factor for clients. Quality of service (keep appointments, response speed and accuracy, no damages) is only a negative decision factor in the case that it does not meet the expected standard. A matchmaking technology like the one we are proposing clearly addresses a market need of clients but it does so at the expense of transporters, who seem to feel threatened by our vision. Support: 3.

11. **Price negotiation.** Some experts stated that price negotiation is a cornerstone of the business. A system that does not allow for negotiating is not acceptable. This finding does not affect our assesment of problem relevance but points toward a negotiation feature. Support: 2.

12. **Quality dimensions.** Some experts stated they would not want to compete world-wide with everyone because of price sensitivity, but they felt they had a higher-quality offering than cheaper alternatives. It would be necessary for open competition to be able to advertise verifiable quality dimensions such that clients understand the higher price. This finding shows that the technology should provide the possibility to differentiate offerings from each other in multiple dimensions and to make verifiable claims about service/offer quality. The deeper problem this finding touches upon is that apart from price, clients often do not know about aspects of quality they require, either because these requirements are implicit or because clients lack experience. Therefore, in addition to

providing a means for verifiable claims, it would seem beneficial if the technology provided a means for conducting a conversation with the client about service qualities with the goal of educating the user about alternatives so as to allow them to make a more informed decision. Support: 2.

13. **Wrong Assumptions.** In some cases, important information is present only in an implicit form. For example, the recipient of a shipment of agricultural products may only be able to unload a dumper truck, not any other kind of truck - but this fact is assumed to be known to the transporter, which may lead to the wrong kind of truck being used, incurring delays and additional cost upon delivery. This finding provides support for machine-interpretable, standards-based, automatic information interchange that may uncover incompatibilities like the one above automatically. Support: 1.
14. **Freight exchanges.** Transporters are reluctant to use freight exchanges to find new assignments because the prices they can ask there are very low, to the point that it is cheaper to make an empty return journey than to obtain a contract there. This finding may be seen to disconfirm relevance of our work, as the technology could have a similar effect for transporters overall. It is possible, however, that this effect is related to systems that focus mostly or solely on price and that in this case, the solution features discussed in connection with Finding 12 (quality dimensions) could ease the situation for transporters. Support: 1.
15. **Contract negotiation.** Contract negotiation may not be necessary, but when it is, it can be a lengthy and error-prone phase. In some cases, one side simply dictates the contract's conditions. This is the case when a transport partner is being searched for a longer term business relationship, and transporters make bids, or when a transport company offers standardized services together with standardized terms. In some situations, contracts have to be set up for individual transport assignments, which is usually done using MS Word documents sent back and forth via e-mail. At least one of our interview partners expressed the hope for a better integrated solution that allows for more clarity during this phase. Support: 1.

We judge Findings 2, 3, 5, 7, 9, and 13 as supporting problem relevance. Findings 1, 4, 6, and 8 do not clearly refer to problems calling for a solution. Rather, they describe current strategies evolved to avoid friction as much as possible.

Insofar, we would not say they contradict problem relevance, but we cannot include them in the set of supporting findings, either. Findings 10 and 14 disconfirm problem relevance from the point of view of the transporters because the solution may mean more pressure on prices. Findings 11, 12, and 15 are interpreted as being neutral with respect to problem relevance.

In total, the interviews do seem to indicate the problem we are tackling is relevant. This assessment is backed up by the fact that twelve experts said they would be happy to try out our system and six welcomed our our plans explicitly. We were able to collect information about expectations and requirements that may lead to future developments, most of which need further refinement. In our design process, we focus on fundamental functionalities first, which are generally taken for granted in such interviews and therefore do not come up as important topics. Therefore, the full consequences of the findings on concrete design decisions may materialize at a later point in the process.

In the following, we present our approach to the technical design of the solution. Any influence of our interview findings will be noted explicitly.

4 Knowledge Base

4.1 Web of Needs

The main building block for our solution is the Web of Needs (WoN) technology (Kleedorfer, Busch, Pichler, et al., 2014). Its overall functionality is depicted in Figure 1. Participants publish supply and demand on a de-centralized network (1a, 1b), on servers (*WoN nodes*) of their choice, in a standardized form such that they are machine-readable and can be found by dedicated, independent *matching services* (2) that identify suitable (supply,demand) pairs and inform them by sending a *hint* message (3). The participants controlling the supply and demand objects can choose to establish a communication channel and exchange messages.

WoN is domain-independent, focusing on providing a framework for common interaction patterns while leaving space for creating domain-specific specializations. In order to achieve this goal without introducing a break between the framework and the content, WoN is entirely based on RDF (Manola and Miller, 2004) as a data description language and the Web as its basic framework: the whole data

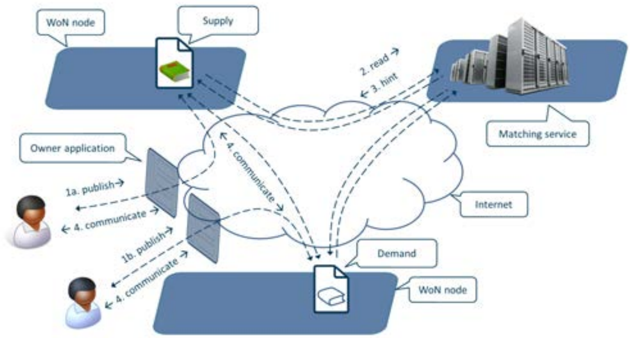

Figure 1: Interaction diagram showing interactions of two participants and a matching service in Web of Needs. Image is based on Kleedorfer, Busch, Huemer, et al., 2016, licensed under CC-BY-SA 4.0.

structure, comprising supply, demand, their connections and the complete data exchange are represented as linked data (i.e., RDF that can be accessed on the Web, Bizer, Heath, and Berners-Lee, 2009). The particpant's privacy is protected by representing needs (supply or demand), and not users, in the system; each need can have a dedicated cryptographic key pair which is used to verify any message it sends. The integrity of the communication history is automatically ensured by iteratively signing a hash derived from the past message history (Kleedorfer, Panchenko, et al., 2016). This approach allows for using the communication channel between two participants as a shared RDF database to which they can both add data by sending messages, but not delete or otherwise change past data. By representing the content domain adequately in RDF, this system allows for cooperatively creating and manipulating a shared machine-interpretable model of any business transaction.

The immutability property of WoN conversations makes it look similar to blockchain systems at first glance (Nakamoto, 2008). The immutability property is not quite as reliable in WoN as it is in a popular blockchain: signatures are only made by participants of a conversation, as well as by the WoN nodes they use, so threat model and trust model differ greatly between blockchain and WoN. It remains to be seen if trust and threat models in WoN are acceptable for practical applications;

it should be noted, however, that WoN provides functionality on a different level than blockchains: expressing supply and demand, matching, and messaging are not concerns of blockchain systems.

The reason for WoN to include a cryptograhpically assured message history is the observation that in practice, the conversation that precedes a transaction must be interpreted as the contract both parties agree to in the absence of any more formally defined agreement. It is therefore important that they can rely on an unchangeable message history in order to prove what has been agreed to in the event of a dispute. In order to achive this, it is sufficent to have each others' signatures on each message.

4.2 i-Cargo Ontologies

The EU project i-Cargo (Hofman et al., 2016; A. Garcia, 2015), finished in 2015, is a highly relevant research endeavour we can build upon. One of the goals of i-Cargo was the creation of an open freight management ecosystem spanning multiple organizations and countries. The project produced a number of artifacts that can be re-used for our work, most importantly a collection of ontologies specifically developed for the transport sector (Daniele and Ferreira Pires, 2013). These ontologies are the Logistics Core Ontology *LogiCo*(Daniele, 2013a), the Logistics Services Ontology *LogiServ*(Daniele, 2013b), and the Transport ontology (Daniele, 2013c). They provide a basis for describing the entities relevant for the transport domain using RDF. Using these ontologies, it is possible to describe such entities as consignor and consignee, means of transport, consigments and transported goods, packaging, delivery and pick-up options, transportation requests and transport execution plans.

5 Artifact Design: Open Logistics Networks

The application and extension of WoN to support transport and logistics creates a virtual medium in which any number of real-world market participants can be represented in self-organized open networks, hence the name of our project, *Open Logistics Networks*.

The general idea is to describe the relevant entities according to the LogiCo, LogiServ and Transport ontologies (or possibly according to simplified versions thereof), to place them inside the needs according to the Web of Needs approach, and to publish those needs on the Web.

Figure 2 shows a transport-related interaction diagram to illustrate this approach. Matching services can use the domain specific descriptions for accurate matching and allow the needs to establish an RDF-based communication channel. Each such connection naturally gives rise to an RDF model that both parties have access to via HTTP. It consists of the set of RDF triples defining the needs and the triples exchanged in the communication channel. If additional resources are referenced in any of these triples, they are added to the shared model as well.

For example, consider an example motivated by Finding 13 (wrong assumptions), with one need describing the delivery event for a consignment of oil seed at an oil mill, seen from the side of the oil mill. It references an RDF description of the technical capabilities for unloading. The connected need describes the delivery event as seen from the transporter, linking to an RDF description of the vehicle, among other details. Both needs have access to the union of all these triples, all of which have traceable provenance information. If information is missing or needs to be changed, it can be requested and provided on the communication channel in the form of RDF triples. Any state change in the shared transaction (e.g., a change to the expected time of arrival) is also represented as new triples that are added to the channel. An actor organizing a bigger part of the transport chain controls not just one, but a number of such needs, which are naturally combined in one RDF model that just covers a larger part of the transport transaction chain than the models accessible to each of the other partners.

In the remainder of this chapter, we describe adaptations required for applying WoN in transportation use cases. The interested reader will notice that none of these topics are uniquely specific to transportation. They must, however, be dealt with before we can tackle domain-specific functionality that addresses problems revealed in our interviews.

5.1 Service Descriptions

The basic element of the Web of Needs are entities representing concrete interest in a transaction, for example, someone may offer a book for sale, and another user wants to obtain a book. Both users could express their intention in the form of a *need*. Both users would get a hint message from a matching service and engage in

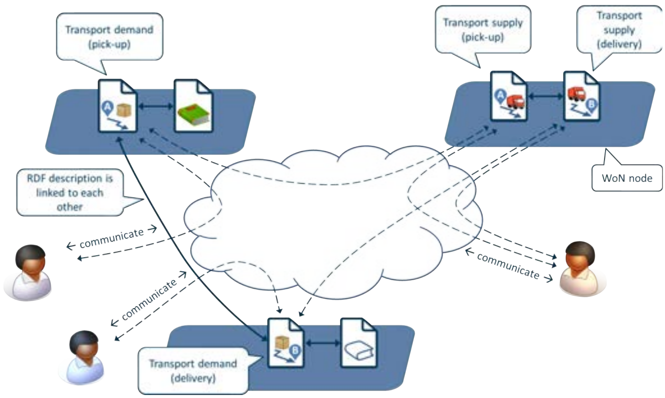

Figure 2: Interaction diagram showing transport specific interactions of consignor, consignee, and transporter in the Web of Needs. In the depicted situation, consignor and consignee have agreed to send the consignment (the book), and publish needs representing the transport and the part they each take in it. The transporter controls needs representing pick-up and delivery. The diagram shows how messages are routed between transporter, consignor and consignee. Image by Kleedorfer, Busch, Huemer, et al., 2016 is licensed under CC-BY-SA 4.0.

a conversation. Both sides use the need object to maintain a reference to that specific business transaction. In the case of general service offerings, however, this pattern is not sufficient. A company offering transport services in a given region could publish an object in WoN, receive hints and establish connections with its clients using that object. This would lead to this object collecting more and more connections over time, possibly impacting data management and application performance. Therefore, we decided to enable a new interaction pattern: a need that creates new needs programmatically for each specific case. In analogy to the concept of a *factory* in software development, an object that creates other objects, we call these special needs *factory needs*.

General service offerings can be represented as factory needs that are informed of any new, potential transaction partner. For example, if the service to be offered is a courier service, the factory need is informed whenever there is a potential client who wants a package delivered. The client, however, should not be informed of just any existing service announcement. They already stated their need and expect to be contacted with concrete offers, not links to services that they might want to explore. Upon being informed of the existence of a potential client, the logic behind the factory need is activated and makes a concrete offering (possibly taking into account situational factors such as current traffic, concurrent requests, or available resources). This concrete offering is represented by the newly created need object, which initiates a connection with the client's need.

Such a scenario requires different matching logic than the symmetric case that had been possible in WoN, a case in which both needs in a match are notified of the match. In the case of factory needs, only the factory should be notified. This requirement caused us to extend the way matching works in WoN such that by default, both parties are notified, but a party can choose to suppress notification for the counterpart as well as the notification for itself. This change was made to the prototypical implementation and tested functionally. Though not a full solution, the fact that one can now define that others should not be notified of one's needs, may contribute to easing the issue raised in Finding 4 (Privacy).

5.2 Information Requirements

As described in Finding 13 (wrong assumptions), the information used for matching is not necessarily identical with the information needed to execute a transaction. In some cases, all the needed information is present when the match occurs.

In other cases, additional questions need to be asked. The fact that the whole data exchanged between participants, including their initial need descriptions is available to both sides as RDF, it is possible to query this data in order to see if the required information has already been stated or not. Based on that property of the system, it is possible for a participant to define information requirements in a declarative way. When a connection is made, the information requirements are automatically checked and missing information is identified. User interfaces can use this information to generate interface components (e.g., forms) to elicit the missing information. User agents may be able to fill in missing information automatically from personal data stores.

In order to realize a sytem that allows participants to define their information requirements, we need to be able to formulate and check them automatically. We plan to use SHACL (Knublauch and Kontokostas, 2017) for this aspect of WoN. SHACL is a formalism for defining *shapes* that an RDF graph can be validated against, the shapes themselves are written in RDF. This allows a need author to include SHACL in the need description, and any party with access to the conversation content can evaluate the content against the shapes. Transmitting the information requirements (shapes) in declarative syntax instead showing a service-defined user interface (e.g. a HTML form) allows for great flexibility; user agents can choose the user interface technology for eliciting the required information from the user. Moreover, SHACL allows for referencing shapes from any Web location, which allows for re-use of shapes and thus an avenue for standardization of distinct use cases, as well as the evolution of such standards. A complete prototypical implementation is to follow.

5.3 Message Retraction

The functionality of information requirements has to operate on a higher level than the level of simple message exchange - one might call it the level of meaning exchange. Each new message contributes its content (RDF triples, grouped in named RDF graphs) to the meaning of the conversation. Sometimes, participants need to change the meaning, for example, to correct a mistake. Therefore, the communication protocol allows for a *retraction message* that links to a message already contained in the conversation, which is thereby marked as retracted. Each participant can only retract their own messages that were sent earlier. Retract messages themselves cannot be retracted. The effect of retraction is that the payload of each retracted message is disregarded in further operations. This planned feature would contribute to functionality that expects users to make and correct mistakes, such as the issues raised in Findings 2 (digitalized communication), 15 (contract negotiation), 5 (appointments), and 11 (price negotiation).

5.4 Distributed Transactions and Long-Running Work

Especially in the context of multi-modal transport, it is required to coordinate more than two parties in order sucessfully to plan and execute the transport. In addition to multiple parties being involved, such an endeavour can span a time of weeks or even months from initial planning to the final delivery. Both aspects make the concept of long-running work (Bocchi, Laneve, and Zavattaro, 2003) suitable for representing such processes. We decided to use the protocol logic defined by WS-BusinessActivity (WS-BA) to model interconnected and possibly nested activities of multiple business participants. As part of such a plan, a need assumes the role of the WS-BA coordinator vis-a-vis the needs that represent possible solutions for the problem. Vis-a-vis a higher-level aggregation node in this plan, that need assumes the role of a WS-BA particpiant.

In order to realize such a need in WoN, in either role specified by WS-BA, it is possible to use server-side logic that is invoked for an incoming message after the mandatory logic realizing the basic protocol has been executed. The need thus implements the state machine prescribed by the WS-BusinessActivity protocol specification.

This system of states and state-changing messages is shared between participants and can at all times be used to determine and influence the state of the distrbuted work. The option to add sub-goals to an overall plan may be one of the building blocks for an integrated appointment making sub-protocol, addressing the situation mentioned in Finding 5 (appointments), and it could be used to realize linked conditional needs that find a one way feight and the return freight simultaneously as required by Finding 9 (return freight). There is an experimental implementation of this feature that will be overhauled.

5.5 Expressing Agreement

In order for transactions or long-running work to function legally, it is required that the two parties involved set up a contract. Theoretically, a spoken agreement is enough to fulfil this requirement; in practice, though, contracts are written and their contents are an important phase during negotiation. Finding 15 (contract negotiation) hints toward the fact that a unified method of contract negotiation may be beneficial for all participants.

The communication channel established by our technology between the participants retains all messages exchanged in a manner that makes the message history unambiguous and unchangeable. It is thus a suitable medium for contract negotiation as it can always be established who said what in which order.

To allow for negotiation, we introduce the possibility to send a special message that marks earlier messages as *proposed*. The other participant has the option to send an *accept* message, referencing the proposal, thereby creating an agreement. The agreement is identifiable by the URI of the accept message. For calculating the agreement's content, only the message history before the accept message is considered. Consequently, retraction has no effect on agreements. They can be canceled by either side by sending a message that *proposes to cancel* an agreement and the counterpart accepting that proposal. At time of this writing, the protocol has been designed, but not yet implemented.

6 Conclusion and Future Work

In this work we describe the current state of our iterative design process with the overall goal of a de-centralized, open, Web based transportation infrastructure. We use expert interviews to identify business needs and assess problem relevance. Addressing these needs, we propose a design for the most fundamental functionalities needed to achieve our overall goal. Two aspects relevant for practical application have been left aside so far, namely payment information integration and reputation management. We identified both aspects as relevant at the outset of the project; our interviews arguably support these features as well: Findings 1 (trust) and 12 (quality dimensions) quite directly point toward reputation management, and a number of business interactions (e.g. high-frequency transport described in Finding 8 (framework agreements)) may be greatly improved if payment was integrated in the communication instead of being handled in an independent channel.

In line with the iterative approach, we are striving for applying the technology for simple transport problems at first, while gathering requirements for more complex situations and gradually implementing solutions for them. Practical evaluation of the designed artifacts in real-world applications and follow-up interviews and workshops are planned for later development phases.

Acknowledgements

This work would not have been possible if it had not been for invaluable ideas and criticism contributed by the research team at Studio SAT, which currently includes Heiko Friedrich, Fabian Suda, Kevin Singer, and Soheil Human. We are indebted to Laura Daniele for sharing her knowledge of the i-Cargo ontologies and to the domain experts who provided valuable insights during our interviews. Special thanks go to Dominik Kovacs of DoKo Agromarketing for introducing us to the community of agricultural commerce. We are also grateful for all contributions to the discussion on the topic of negotiation in the semantic Web mailing list.[3].

Financial Disclosure

This work is funded by the Austrian Research Promotion Agency (FFG) under the project *Open Logistics Networks (OLN)* of the Program *COIN - Cooperation and Innovation*.

References

Airbnb (2017). URL: https://www.airbnb.com/.

Bizer, C., T. Heath, and T. Berners-Lee (2009). "Linked data-the story so far". In: *International Journal on Semantic Web and Information Systems (IJSWIS)* 5.3, pp. 1–22.

Bocchi, L., C. Laneve, and G. Zavattaro (2003). "A calculus for long-running transactions". In: *Formal Methods for Open Object-Based Distributed Systems*. Springer, pp. 124–138.

Daniele, L. (2013a). *Logistics Core Ontology*. TNO. URL: http://ontology.tno.nl/logico/.

Daniele, L. (2013b). *Logistics Services Ontology*. TNO. URL: http://ontology.tno.nl/logiserv/.

Daniele, L. (2013c). *Transport ontology*. TNO. URL: http://ontology.tno.nl/transport/.

Daniele, L. and L. Ferreira Pires (2013). "An ontological approach to logistics". In: *Enterprise Interoperability, Research and Applications in the Service-oriented Ecosystem, IWEI'13 Proceedings*. Ed. by M. Zelm, M. van Sinderen, and G. Doumeingts. ISTE Ltd, John Wiley & Sons, Inc., pp. 199–213.

[3] See https://lists.w3.org/Archives/Public/semantic-web/2017Jul/0004.html [2017/07/07]

DiCicco-Bloom, B. and B. F. Crabtree (2006). “The qualitative research interview”. In: *Medical education* 40.4, pp. 314–321.

Garcia, A. (2015). *iCargo - Intelligent Cargo in Efficient and Sustainable Global Logistics Operations*. ATOS Spain SA. URL: http://cordis.europa.eu/project/rcn/100869_en.html.

Hevner, A. R. (2007). “A three cycle view of design science research”. In: *Scandinavian journal of information systems* 19.2, p. 4.

Hevner, A. R., S. T. March, J. Park, and S. Ram (2004). “Design science in information systems research”. In: *MIS quarterly* 28.1, pp. 75–105.

Hofman, W., M. Punter, H. Bastiaansen, E. Cornelisse, S. Dalmolen, Z. Palaskas, B. Karakostas, J. Gato, J. Garcia, et al. (2016). “An interorganizational IT infrastructure for self-organization in logistics: situation awareness and real-time chain composition”. In: *International Journal of Advanced Logistics* 5.2, pp. 101–115.

Kleedorfer, F., C. M. Busch, C. Huemer, and C. Pichler (2016). “A Linked Data Based Messaging Architecture for the Web of Needs”. In: *Enterprise Modelling and Information Systems Architectures* 11.3, pp. 1–18.

Kleedorfer, F., C. M. Busch, C. Pichler, and C. Huemer (2014). “The Case for the Web of Needs”. In: *Business Informatics (CBI), 2014 IEEE 16th Conference on*. Vol. 1. IEEE, pp. 94–101.

Kleedorfer, F., Y. Panchenko, C. M. Busch, and C. Huemer (2016). “Verifiability and Traceability in a Linked Data Based Messaging System”. In: *Proceedings of the 12th International Conference on Semantic Systems*. SEMANTiCS 2016. Leipzig, Germany: ACM, pp. 97–100.

Knublauch, H. and D. Kontokostas (2017). *Shapes Constraint Language (SHACL) - Proposed Recommendation*. Tech. rep. [Last accessed on 2017/07/06].

Manola, F. and E. Miller (2004). *RDF Primer*. Tech. rep. [Last accessed on 2016/06/06].

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*.

Uber (2017). URL: https://www.uber.com/.

UNECE (1956). *Convention on the Contract for the International Carriage of Goods by Road (CMR)*. Tech. rep. Geneva: United Nations Economic Commission for Europe (UNECE).

UNECE (2008). *Additional Protocol to the CMR concerning the electronic consignment note (e-CMR)*. Tech. rep. Geneva: United Nations Economic Commission for Europe (UNECE).

Varvasovszky, Z. and R. Brugha (2000). “A stakeholder analysis”. In: *Health policy and planning* 15.3, pp. 338–345.

Lead-time Optimization Potential of Digitization in Air Cargo

Benjamin Bierwirth[1], Kai-Oliver Schocke[2]

1 – Hochschule RheinMain

2 – Frankfurt University of Applied Sciences

*The air cargo supply chain consists of several parties: the forwarders collect air cargo shipments and consolidate these shipments in regional warehouses all over the continent. They decide upon the export airport and bring it there to consolidate all shipments in their air cargo hub - warehouse according to the chosen flight. Using local truckers, the shipments, consolidated by airline, are forwarded to the handling agents to load air cargo containers or to build up air cargo pallets. The containers or pallets are brought to the apron and loaded into the planes. There is not a single chain existing; the parties involved are part of a dynamic n * m * o network which is fixed with every single shipment. The problem addressed in this paper is to document the waiting times at the level of the handling agents. Own, long time research at Frankfurt International Airport shows, that the waiting time for the trucker in front of handling agents warehouses significantly influence the lead-time for shipments. We identify the barriers to a faster adaption of digitization, which is currently around 30% in Frankfurt. Quantifying the impact of waiting times and required warehouse space due to long lead-times allows for a cost estimate.*

Keywords: Air Cargo; Lead-Time Reduction; Digitization; Air Cargo Supply Chain

1 Introduction

1.1 Problem description

In this paper, we address the optimization potential in air cargo handling by using electronic data exchange and the barriers that hinder a faster development of digitization. Digitization is expected to be an important enabler to optimize the physical shipment flow between forwarder and cargo handling agent and reduce existing waiting times.

As waiting time costs accumulate to millions of euros per year and the existing IT systems provide interfaces to exchange information between the participants of the supply chain and other solutions like cargo community systems exist, we try to identify the reasons for the slow adaption of digitization in the air cargo supply chain, mainly for forwarders and cargo handling agents.

Based on a survey within the members of the air cargo community of a major hub airport we can show that the benefits of electronic data exchange in the air cargo supply chain are well understood, but other barriers hinder further development.

1.2 Air Cargo Supply Chain

Air cargo is the fastest mode of transport, but also the most expensive one. It is therefore used in emergencies or in the global supply chain of high value goods. General air cargo has to be differentiated from express and parcel services – e.g. from DHL or UPS – as these companies mostly use dedicated air and road transport networks and facilities. The air cargo supply chain on the other hand consists of several parties: the forwarders collect the shipments from the shipper and consolidate these shipments in regional warehouses all over the continent. They decide upon the export airport and bring it there to consolidate in their air cargo hub-warehouse all shipments according to the chosen flight. Using local truckers, the shipments by airline are forwarded to the handling agents to load air cargo containers or to build up air cargo pallets. The containers or pallets are brought to the apron and loaded into the planes (see figure 1).

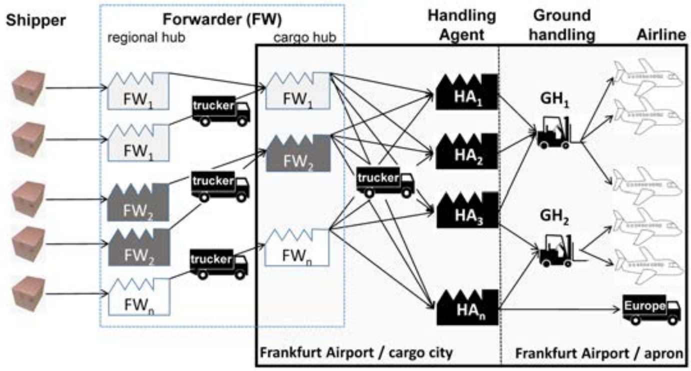

Figure 1: Air Cargo Supply Chain at Frankfurt Airport (here: export process)

1.3 Legal Situation between Forwarder und Handling Agent

The transportation is based on a contract between shipper and consignee where the respective party – according to the chosen INCOTERMS – orders the forwarder to organize the transportation. Besides of having outsourced various steps in the ground transportation. The forwarder is responsible for contracting an airline. The airline has their own contracts with handling agents at the respective airports (see figure 1). This leads to common supply chain management problem that at the handling agent's warehouse to parties meet which do not have a direct contractual relationship and therefor show only limited interest in mutual optimized solution. In difference to many production or distribution supply chains, a leading partner that forces its partners into a hierarchical supply chain management is missing. With many partners of various sizes and a volatile setup, also a consensus based supply chain approach is difficult to realize.

1.4 Digitalization in Air Cargo

The air cargo shipment has to be accompanied by many shipment papers, which are necessary for e.g. declaration or description of the content. This paperwork

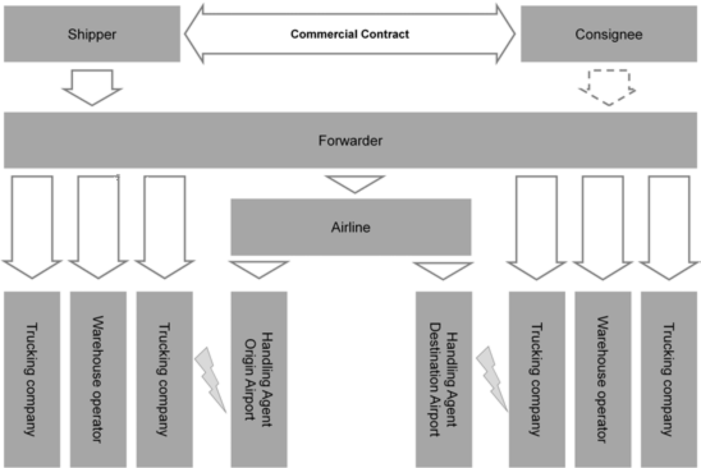

Figure 2: Contracts in the air cargo supply chain

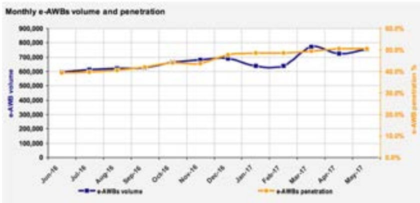

Figure 3: IATA eAWB development (International Air Transport Association, 2017)

could be done electronically. The respective factors (papers transmitted electronically/papers in total) in Frankfurt differs from airline to airline, from forwarder to forwarder, but does not exceed 30% so far. Penetration rate of electronic airway bills (eAWB) just reached the global 50% mark and is lagging behind the expected development. Several activities have been conducted, e.g. by the International Air Transport Association (IATA), or the local collaboration platform fair@link to increase the digitalization share, but did not show fundamental success by now (see figure 3).

1.5 Weekend Peak

Around half of all cargo is transported on passenger planes, which often offer a daily (or better) service to major destinations. Nevertheless, cargo volume typically peaks on weekends. As most businesses (shippers and consignees) do not operate on weekends the shipments arrive on Friday or Saturday latest for export and the incoming shipments will be picked up Monday morning. The weekend peak is especially challenging for the handling agents, as air cargo shipments are typically booked on short notice (see figure 4).

1.6 Key Performance Indicators in Air Cargo

In air cargo handling, competitiveness can be defined by lead-times and related costs. Lead-times directly influence the related costs as shorter lead-times re-

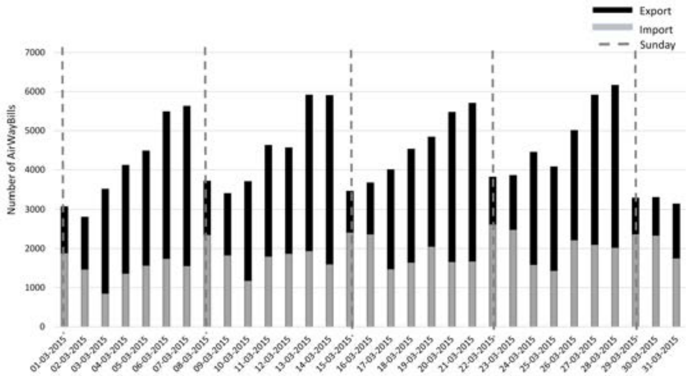

Figure 4: Weekly cargo volume distribution (n = 102,793 Airway Bills of March 2015 = 40% of Volume of Frankfurt Airport)

duce the number of stored shipments in the warehouse and – besides being less complex – allow for an increase in efficiency.

The lead-time concerning this paper is defined to be the difference between the arrival time of the truck at the office of the handling agent (landside) and the transportation of the shipments to the plane (airside) for the export process. The lead-time in imports is measured between the arrival of the shipments at the handling agent's warehouse on the airside and the pickup by the forwarder.

1.7 Structure of the paper

This paper is organized as follows: The related literature from the areas of air cargo, supply chain management and operational logistics is presented in section 2. A detailed problem description follows in section 3. It is based on other research about truck waiting times and average lead-times in handling agent warehouses before detailing the theoretical benefits of digitization and potential barriers or risks.

Section 4 contains the relevant information about the setup and structure of the survey, which is followed by the presentation of the most important results in section 5. These are transformed into a benefits-barriers-model. Section 5 ends with a critical appraisal of survey and model. The last section contains a summary and directions for further research.

2 Related Literature

2.1 Aviation and Air cargo

Research in the Aviation industry is mostly focused on the passenger transport (Wittmer, Bieger and Müller, 2013).

Specifically in air cargo networks only few current research papers are found (Sieke, 2010; Vancroonenburg, et al., 2014; Feng, Li and Shen, 2015a; Zhang, et al., 2017) which contain mostly pure theoretical considerations without containing real data.

Chen et al consider the choice of optimal transshipment-hubs (e.g. that of the export port or the airport) from the shippers and forwarders perspective (Chen, et al., 2017). Besides quantitative factors such as costs and transportation distance, location-specific qualitative elements are taken into account as well. Feng (Feng, Li and Shen, 2015b) gives an up-to-date overview of the air cargo operation. The examined questions are about the optimization of the layout or seperate processes (Frye, 2003; Chan, et al., 2006; Yan, Shih and Shiao, 2008; Bierwirth, 2009; Lau, et al., 2009; Selinka, Franz and Stolletz, 2016). Other authors examine the Revenue Management in air cargo (Hellermann, 2006; Pfeffer, 2015; Chao and Li, 2017).

There are some, partially unpublished, preparatory works by the authors that talk about the investigation of the processes at Frankfurt Airport (Wagschal and Schocke, 2012; Schocke, 2013; Hertelendy, et al., 2015; Wegener and Schocke, 2015; Bierwirth, Höhl and Winning, 2016; Schocke and Koch, 2017).

2.2 Supply Chain Management

Beside Air cargo specific processes research and publications regarding the benefits of information exchange in supply chain management is relevant for the deduction of digitization benefits.

The majority of the publications focuses on a classic Supply Chain and the cooperation of supplier, producer, distributor and examines the effects of fluctuations in demand and the resulting costs (Schulze, 2009; Barros, et al., 2015; Marinagi, Trivellas and Reklitis, 2015; Rached, Bahroun and Campagne, 2015). Walter (Walter, 2015) examines the "Exchange of information in the maritime transport chain – investigation of process performance in the data flow of capacity utilization" in very similar and comparable aspects. Aspects of empirical investigations were transferred to air cargo based on this publication.

Only in Walter (Walter, 2015), the relations of associates inside the transport chain (forwarders, carriers, other logistics service providers) were object of a publication. The quantification of use mostly occurred over simulation models and calculations and was only seldom linked to empirical analyses.

Consisting approaches from the SCM-theory prove that a corporate planning policy such as e.g. a mutual optimal order- and production policy can be determined in ways of minimizing the sum of total costs from costumer and producer (Sucky, 2004).

2.3 Operational bottlenecks

In theory and practice, loading ramps are known to be a bottleneck of transport logistics. Many practice-oriented publications of the recent years in this context make it clear that friction losses occur in the interfaces of processing (Semmann, 2012). The site operating companies, here Handling Agents, aim for maximal capacity of their ramps and a continuous flow of cargo (Semmann, 2012). Ramp management concepts aim for an optimization of the use of the ramps. In practice, the active management is often not transcribed in consideration of all boundary conditions, which leads to efficiency losses. There losses can affect the daily planning substantially of the site operating and cargo carrying companies and are not only complained about in practice but also talked about in a special report of the federal office for freight transport (Semmann, 2012).

3 Problem Description

Firstly, we describe results of the research about the status, which give an indication about the optimization potential. Afterwards the benefits of digitization and electronic data exchange will be detailed and potential risks discussed.

3.1 Current status and deficits

According to proven supply chain management theory, the exchange of information between supply chain partners – in our case the forwarder, the airline and the handling agent – could accelerate handling as all parties can prepare in advance and optimize their use of resources. The minimum improvement would be the time saving of entering shipment or airway bill data and avoidance of printing and paper costs. Beyond these simple references, a more detailed approach regarding the benefits of electronic data exchange is missing. Besides formulating, the urgent need for digitization related risks as well as needed competencies and capabilities necessary for successful digitization are unknown.

Earlier research showed that the parties involved (handling agents and forwarders) use IT systems, which are capable of exchanging information in various formats and to a centralized platform as well as over bilateral interfaces.

An on-site observation of the truck docks of several handling agent warehouses over a period of 36 hours at 1st and 2nd of June, 2017, led to the calculation of average truck lead-times.

The overall lead-time for handling agent 1 is 186 minutes, for handling agent 2 209 minutes and for handling agent 3 is 164 minutes. Supposing an identical mix of shipments and defining the shortest length per segment as a benchmark (e.g. 39 minutes for handling agent 2 company arrival - office entrance), the benchmarking lead-time is 88mins. Consequently, significant waiting times can be calculated: at least 50% of the overall lead-time is waiting time (see figure 5).

As part of the observation, the truck drivers have been asked, if they announced their arrival (e.g. using a truck dock scheduling system) or if they have been informed about the current operating grade at the ramp. Just 25% of the truck driver use existing ramp scheduling systems and 25% are informed about current operating grade. This happens although 80% of the truck drivers are equipped

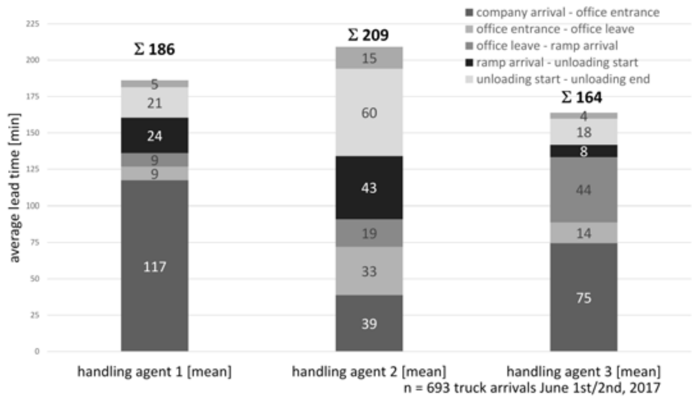

Figure 5: Truck waiting times as part of lead-time

with a smart phone. Exchange of information does not happen and leads to long waiting times.

Beside the cost of waiting times, the missing information about the shipments loaded onto each truck some shipments miss their booked flights which causes extra costs. Expectation of several partners of the air cargo supply chain is that with electronic data exchange and a truck slot time management system these backlogs (see chapter 5).

Apart from observing truck drivers, we collected a set of data from four handling agents and Fraport from March 2015, which covers 40% of the overall tonnage. With this set of data, we are able to calculate the lead-time from office entrance at handling agent until off block (plane leaves its parking position).

The analysis of the lead-times of these 102,793 shipments show that while the mean is almost a day (from delivery to airside departure and airside arrival to pick up) most cargo is delivered or picked up shortly before latest acceptance time (LAT) or after time of availability (TOA). It can be logically deducted that shipments which arrive early or stay long in the handling agents warehouse add to the complexity and may block resources which are needed for time critical shipments. As with the time management system the expectation is the increase the efficiency of the use of resources and faster processes at this external interface with digitization (import: see figure 6; export see figure 7).

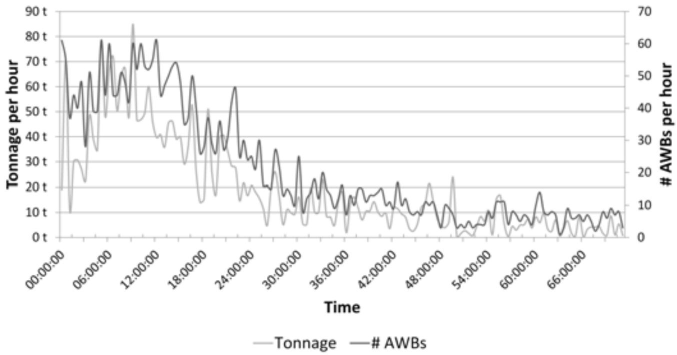

Figure 6: Import lead-times

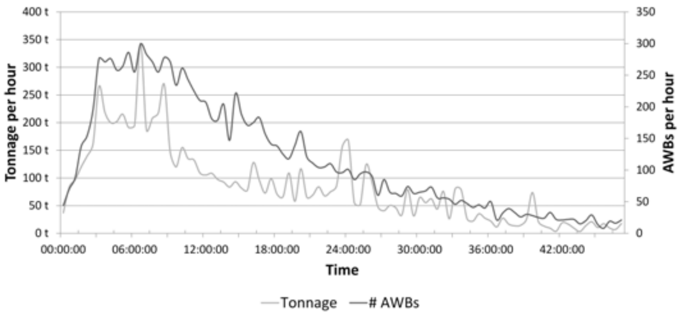

Figure 7: Export lead-times

3.2 Benefits of digitization

As mentioned in the beginning, the overall expectation would be cost saving. However, beside this and the above-mentioned expected increase in resource efficiency further aspects have to be considered as benefits (see figure 8).

Based on a better planning which is made possible by information transmitted prior to truck arrival processes can be aligned and thereby reducing waiting times, so a faster process can be achieved (time). At the same time, the amount of time for re-entering the data can be eliminated. The planning leads to a more efficient use of staff and less waiting times or buffers between various process steps and thereby accelerates the handling.

Reduced lead-times increase the use of truck docks and storage area, so overall capacity of the facility can be increased. The resources involved are used more efficiently at the same time and thereby the marginal costs are reduced.

The benefits regarding the cost perspective is threefold: As already mentioned the cost for re-entering data can be eliminated. This also eliminates possible mistakes and the related effort to correct those. Less mistakes than lead to less effort for searching and/or questions by customers. Additionally the more efficient use of staff leads to reduced costs.

Not only less mistakes are made, but also mistakes could be identified earlier (e.g. if number of packages differ with documentation).

Last factor to be considered should be a positive effect on the image of a handling agent as less mistakes may lead to higher customer satisfaction.

3.3 Risks and required competencies

As the benefits are easy to deduct, although not quantifiable, additional barriers or other missing elements are hindering a faster adoption.

Based on several expert interviews and students' thesis as well as the authors experience over the years, the authors identified risks and competencies that might be crucial for a successful digitization.

A very important aspect is trust in the partners and service providers or fear about the misuse of information provided electronically. This mainly defines the willingness of exchanging data. This aspect than is of course the ability to

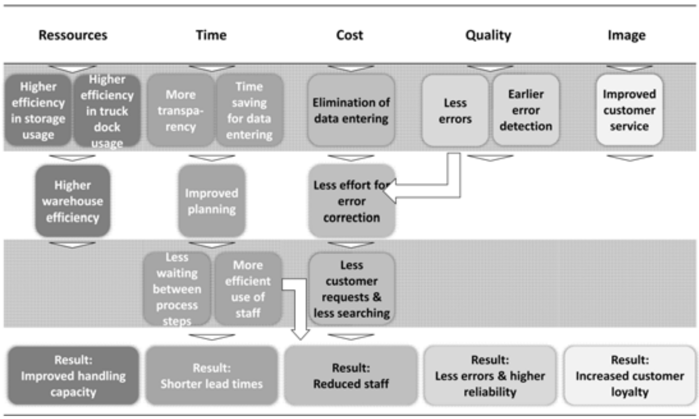

Figure 8: Detailing the benefits of digitization in air cargo

exchange data, which requires technical and management skills – from connecting the systems to explanation of the transformation to the employees.

4 Survey

The survey within the air cargo community was designed to firstly verify the understanding of the formulated benefits of digitization. The second part deals with the other aspects, the risks and competencies such as the digital readiness of partners in the air cargo supply chain and their supply chain thinking.

As electronic data exchange requires at least two parties (sender and receiver), the survey should be relevant for all parties in the air cargo supply chain, and not specified for one group.

The survey consisted of 40 questions which were sent to members and interested parties of Air Cargo Community Frankfurt (ACCF). In total 136 persons were addressed. Prior to that, the questionnaire was pre-tested within in the project team and with selected members of the community. A return rate of 26% could be achieved. The returning questionnaires cover the entire air cargo supply chain (see figure 9)

In the beginning, the participant had to select the company size and its role in the supply chain.

To evaluate the importance of model sub-elements the participants were requested to give their consent or opposition to statements on a scale from 1 to 10 where 1 was defined and indicated as “I totally disagree” and 10 as “I totally agree”. Additionally we integrated open questions and multi-selection questions, e.g. for the type of electronic data exchange that is currently used.

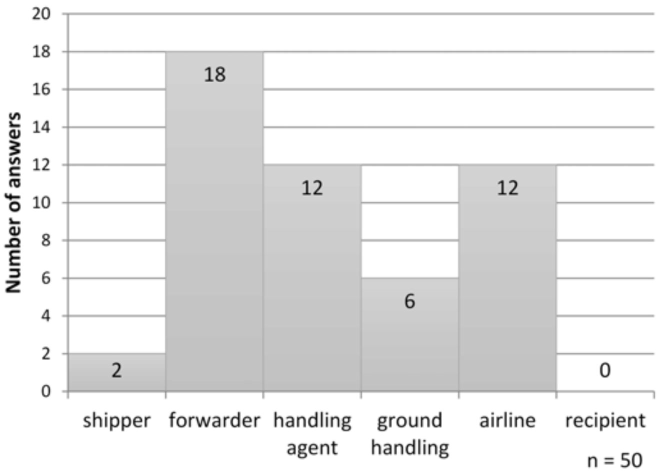

Figure 9: Position in air cargo supply chain of respondent (n=50)

5 Results

5.1 Benefits of digitalization

In part one of the survey, the respondents have been asked for their view on the benefits of digitalization.

Concerning the digital exchange of information, 85% of the respondents reported to already use digital data exchange (see figure 10).

In most cases IT-systems are connected via electronic data interchange (EDI), however, 24% of respondents said they mainly use e-mails with attachments. The tools being used are separated into one third each between the local cargo community system fair@link, bidirectional interfaces as well as other media (here especially e-mail clients)

The advantages of electronic data exchange are clear to the respondents. Digital data exchange improves resource utilization (mean 8,96; STD 1,33), reduces costs (mean 8,55; STD 1,64), improves data quality (mean ,67; STD 1,99) and makes it possible to increase capacity (mean 7,70; STD 2,03). Data exchange also strengthens the image of the company (mean 7.98; SRD 1,58).

5.2 Maturity of Supply Chain Thinking

The importance of general thinking as well as cooperation is being recognized cleary by the companies: The up- and downstream companies in the supply chain are seen as part of the own network (mean 7,58; STD 2,45; see figure 11)

As mentioned before companies see big advantages in electronic data exchange. But there is an obvious gap between desire and reality: Although practically all companies use electronic data exchange not all partner companies are attached (mean 7,58; STD 2,45; see figure 12).

5.3 Data quality

Reasons for the poor penetration of electronic cooperation are widely varied (see table 1).

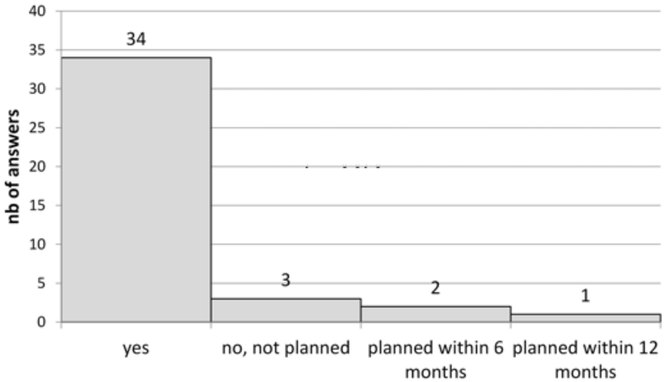

Figure 10: Usage of digital data exchange (n = 40)

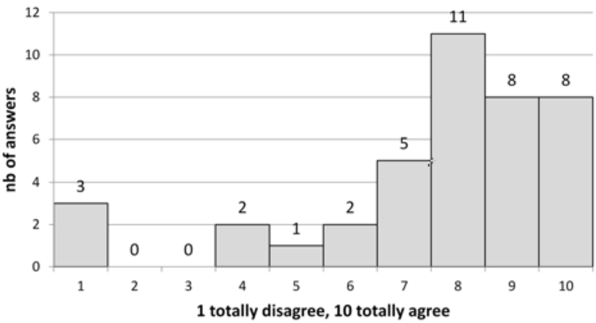

Figure 11: Downstream and upstream companies are part of companies supply chain

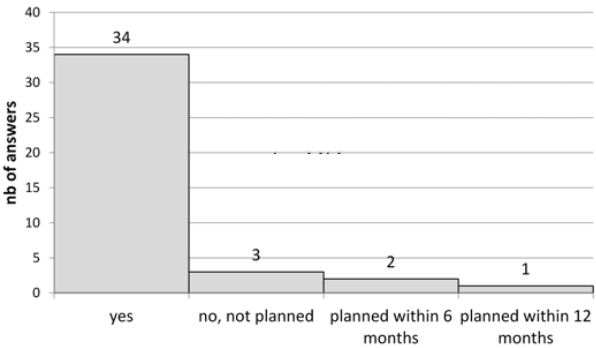

Figure 12: Direct connections between the IT systems of all our partners do exist

Table 1: Reasons for poor electronic penetration

Information we get is …	Mean	STD	Median
In time	5,61	2,38	5,00
Complete	5,74	2,41	6,00
Reliable	5,91	2,31	6,00
Clear and easy to understand	6,14	2,26	6,00
Up to date	6,19	2,32	7,00

The information that is transmitted to the partners is unsatisfactory in several dimensions. Respondents see immense improvement potential in both punctual delivery and completeness and currency. Especially the aspect of reliability of data is seen critically. In addition, the rework of electronically transmitted data needs to be corrected by 26% of the companies.

The advantage of electronic transmission to avoid system breakdowns cannot be verified for sure; IT processes need to be checked manually which can lead to additional costs.

5.4 Risks

The contradiction between wanted and implemented electronic exchange of data can be shown by the means of two additional dimensions. On the one hand, digitization leads to transparency, on the other hand digitization is seen critically due to stronger dependence on IT.

The operative processes in the air cargo industry nowadays are marked by randomness and lack of transparency. The decision which airline sends a consignment is a case-by-case decision, which e.g. contains extensive requests for different airlines (see chapter 2). Through electronic linking of IT systems cargo data can be retrieved directly. At the same time, inefficiencies on individual value levels become visible to the costumer. The companies however become more transparent and therefore better comparable in terms of the temporal component of the processes (see figure 13).

Therefore market transparency will increase, which most of the companies suggest (mean 7,24; STD 1,79). This transparency is seen more as a threat than a chance (mean 4,76; STD 2,74).

These statements are influenced by the thought that many IT projects are obviously unpredictable (mean 5,59; STD 2,58), the confidentiality of data can only be ensured conditionally (mean 5,76; STD 2,76) and one becomes dependent on one service provider due to linkage (mean 6,03; STD 2,78) or the connection is very complex.

In conclusion, a very heterogeneous picture is shown regarding the realization of digitization in the air cargo industry.

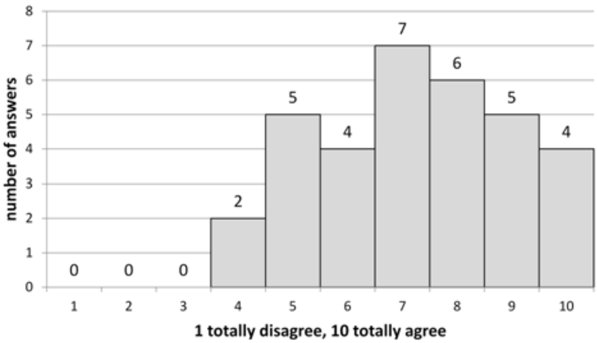

Figure 13: The market becomes more transparent

5.5 Benefits-Barrier-Model for digitization in air cargo

Based on the results of the survey a benefits-barriers-model was developed to reflect the potential benefits of exchanging data and the barriers the might hinder the successful implementation. Therefore, an inverted triangle was chosen to reflect the three perspectives: The five types of benefits can only be realized if the four competencies are present with a basic knowledge and the risk side can be calculated against the benefit (see figure 14).

As mentioned in section 3.3, the risk perspective mainly influences the willingness of a participant to share information. Related to the exchange or distribution of information on an exchange platform additional risks arise:

— The business might become more transparent

— The confidentiality of the information has to be ensured

— The partner may become dependent of the platform and the information provided

The (IT) project risk involves the uncertainty and lacking experience with projects – esp. of smaller partners. This could be solved with external partners providing

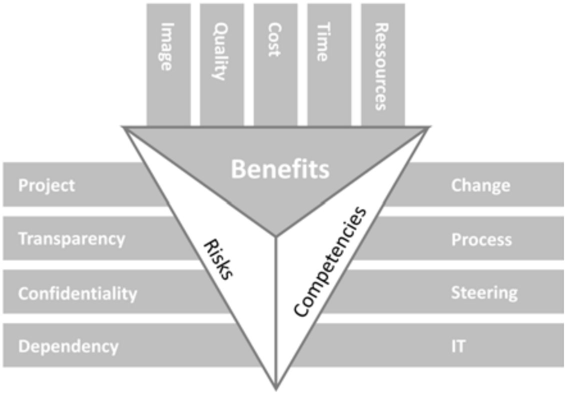

Figure 14: Benefit-Barriers-Model

this experience or by the exchange service provider who includes the project management.

On the competence perspective, a partner has to possess steering and process competencies. The information acquired earlier in the process has to be used to improve planning for example; otherwise, no benefits can be realized. The partners have to understand their IT system and the platform and how it integrates into the overall process and for example, which mobile equipment is needed. This is meant with IT competence. As commonly known digitization changes the working environment so an accompanying change management is essential for a successful installation.

5.6 Critical Appraisal

The model was developed based on a limited sample size of answers from just one airport community. The maturity of competencies is hard to measure and the model so far does not indicate which maturity level has to be achieved to take the competence barrier.

Quantified calculations of the benefits, e.g. from a best practice, are necessary to calculate a business case which is necessary in most companies to justify investments and projects.

6 Conclusion

The air cargo supply chain consists of many partners with individual goals, interests and perspectives. The grade of digitalization in information exchange is poor compared to other industries. We presented lead-time calculations as well as waiting time considerations which show the inefficiency of todays processes. We describe the discrepancy between these inefficiencies and the expectations of the protagonists of the air cargo supply chain.

We conducted a survey which shows that the benefits of digitization and electronic data exchange are understood and agreed upon by all participants in the air cargo supply chain. A positive impact on image and quality can be expected as well as reductions in cost and lead times. Resources can be used more efficiently.

The survey revealed a maturity in supply chain thinking although there is a huge gap between the perception of supply chain thinking and the existing electronic data exchange between the partners.

Beside predicting benefits from digitization and having a supply chain thinking other barriers hinder the development of electronic data exchange. Managers mostly fear the transparency of a digitized supply chain and lack some competencies for making the digital transition.

The results of the survey led to the development of the benefits-barriers-model. The benefits of digitization can only be realized if risks are low and other competencies exist.

Acknowledgements

The authors would like to thank the Air Cargo Community Frankfurt e.V., which coordinated the contact to and the communication with the companies involved into this research.

Financial Disclosure

The present study was financially supported by the research-funding program "HOLM Innovationsfonds" of Hesse's Ministry of Higher Education, Research, and Arts (HO 2014/40).

References

Barros, A. P. d., C. S. Ishikiriyama, R. C. Peres, and C. F. S. Gomes (2015). "Processes and Benefits of the Application of Information Technology in Supply Chain Management: An Analysis of the Literature". In: *Procedia Computer Science* 55, pp. 698–705.

Bierwirth, B. (2009). *Optimierung der Sicherheitskontrolle in der Luftfrachttransportkette aus logistischer Sicht: Vortrag gehalten auf dem Kolloquium Luftfracht und Luftsicherheit, 13. November 2009 Frankfurt/Main*. Praxiswissen.

Bierwirth, B., S. Höhl, and J. v. Winning (2016). *Electronic Air Cargo Supply Chain*. Frankfurt.

Chan, F. T., R. Bhagwat, N. Kumar, M. K. Tiwari, and P. Lam (2006). "Development of a decision support system for air-cargo pallets loading problem: A case study". In: *Expert Systems with Applications* 31.3, pp. 472–485.

Chao, C.-C. and R.-G. Li (2017). "Effects of cargo types and load efficiency on airline cargo revenues". In: *Journal of Air Transport Management* 61, pp. 26–33.

Chen, G., W. Cheung, S.-C. Chu, and L. Xu (2017). "Transshipment hub selection from a shipper's and freight forwarder's perspective". In: *Expert Systems with Applications* 83, pp. 396–404.

Feng, B., Y. Li, and H. Shen (2015). "Tying mechanism for airlines' air cargo capacity allocation". In: *European Journal of Operational Research* 244.1, pp. 322–330.

Feng, B., Y. Li, and Z.-J. M. Shen (2015). "Air cargo operations: Literature review and comparison with practices". In: *Transportation Research Part C: Emerging Technologies* 56, pp. 263–280.

Frye, H. (2003). *Flächenbezogene Optimierung von Luftfrachtterminals: Zugl.: Dortmund, Univ., Diss., 2002*. Logistik für die Praxis. Dortmund: Verl. Praxiswissen.

Hellermann, R. (2006). *Capacity options for revenue management: Theory and applications in the air cargo industry ; with 17 tables*. Vol. Vol. 575. Lecture notes in economics and mathematical systems. Berlin, Heidelberg, and New York: Springer.

Hertelendy, T., T. Gerhardt, H. Frye, and K.-O. Schocke (2015). *Datenmodell für Monitoring und Benchmarking der Cargo City Frankfurt*.

International Air Transport Association (2017). *e-AWB international monthly report May 2017*.

Lau, H., T. M. Chan, W. T. Tsui, G. Ho, and K. L. Choy (2009). "An AI approach for optimizing multi-pallet loading operations". In: *Expert Systems with Applications* 36.3, pp. 4296–4312.

Marinagi, C., P. Trivellas, and P. Reklitis (2015). "Information Quality and Supply Chain Performance: The Mediating Role of Information Sharing". In: *Procedia - Social and Behavioral Sciences* 175, pp. 473–479.

Pfeffer, S. (2015). "Revenue Management in der Luftfracht". Dissertation. Stuttgart: Universität Stuttgart.

Rached, M., Z. Bahroun, and J.-P. Campagne (2015). "Assessing the value of information sharing and its impact on the performance of the various partners in supply chains". In: *Computers & Industrial Engineering* 88, pp. 237–253.

Schocke, K.-O. (2013). *Cargo City 2020*. Frankfurt.

Schocke, K.-O. and S. Koch (2017). *Analyse der Verkehrssituation in der CargoCity unter spezieller Berücksichtigung der Tor 26/31/32*. Frankfurt.

Schulze, U. (2009). *Informationstechnologieeinsatz im Supply-chain-Management: Eine konzeptionelle und empirische Untersuchung zu Nutzenwirkungen und Nutzenmessung: Zugl.: Vallendar, WHU - Otto Beisheim School of Management, Diss., 2009*. 1. Aufl. Vol. Bd. 10. Gabler Research. Wiesbaden: Gabler.

Selinka, G., A. Franz, and R. Stolletz (2016). "Time-dependent performance approximation of truck handling operations at an air cargo terminal". In: *Computers & operations research : and their applications to problems of world concern : an international journal* 65 (2016), pp. 164–173.

Semmann, C. (2012). "Eiszeit an der Rampe". In: *DVZ*, pp. 1–2.

Sieke, H. (2010). *Ressourcenallokation im Luftfrachttransportnetz mit Hilfe einer standortübergreifenden Frachtflusssteuerung: Zugl.: Diss., Technische Universität Dortmund, 2010*. Luftfahrt. München: Verlag Dr. Hut.

Sucky, E. (2004). *Koordination in Supply Chains: Spieltheoretische Ansätze zur Ermittlung integrierter Bestell- und Produktionspolitiken*. Produktion und Logistik. Wiesbaden: Dt. Univ.-Verl.

Vancroonenburg, W., J. Verstichel, K. Tavernier, and G. Vanden Berghe (2014). "Automatic air cargo selection and weight balancing: A mixed integer programming approach". In: *Transportation research / E* 65 (2014), pp. 70–83.

Wagschal, H. and K.-O. Schocke (2012). *Logistische Verkehrsstrukturanalyse am Frankfurter Flughafen*. Frankfurt.

Walter, F. (2015). *Informationsaustausch in der maritimen Transportkette: Untersuchung der Prozessleistung im Datenfluss und der Kapazitätsauslastung*. Wiesbaden Germany: Springer Gabler.

Wegener, K. and K.-O. Schocke (2015). *Verkehrsanalyse Cargo City Süd*. Frankfurt.

Wittmer, A., T. Bieger, and R. Müller, eds. (2013). *Aviation Systems: Management of the Integrated Aviation Value Chain*. Springer Texts in Business and Economics. Berlin: Springer Berlin.

Yan, S., Y.-L. Shih, and F.-Y. Shiao (2008). "Optimal cargo container loading plans under stochastic demands for air express carriers". In: *Transportation Research Part E: Logistics and Transportation Review* 44.3, pp. 555–575.

Zhang, C., F. Xie, K. Huang, T. Wu, and Z. Liang (2017). "MIP models and a hybrid method for the capacitated air-cargo network planning and scheduling problems". In: *Transportation Research Part E: Logistics and Transportation Review* 103, pp. 158–173.

Investigating the Factors Influencing the Acceptance of Fully Autonomous Cars

Ahmed Ziad Benleulmi[1], Thorsten Blecker[1]

1 – Hamburg University of Technology

Once thought of as a product of science fiction, self-driving cars are discussed today as an unavoidable means towards improving transportation systems. In fact, many car manufacturers have announced their plans to deploy highly autonomous cars as soon as 2020; according to the Society of Automotive Engineers (SAE) these vehicles are capable of reacting "even if the human driver does not respond appropriately to the request to intervene (SAE level 4)". There is however a long way to go before fully autonomous cars (SAE level 5) - where pedals and steering wheels are forgone and limitations to driving during severe weather or in unmapped areas are surmounted - are produced. Herein, the overall aim is to study the drivers and inhibitors of autonomous cars' acceptance across cultures with a special focus on the different risks that might deter consumers from using highly and/or fully autonomous cars. After an extensive reviewing of previous works, a research model based on UTAUT2 was developed and accordingly an online survey was conducted in the US and in Germany; 313 valid answers were collected and analyzed. The findings presented here have serious implications both on the academic field as well as the industry, especially in regards to the roles that risks, culture and gender play in the acceptance of fully autonomous cars.

Keywords: Fully Autonomous Cars; Technology Acceptance Models; PLS SEM

1 Introduction

According to the World Health Organization (WHO), car accidents rank within the top causes of death of people worldwide and rank first if we only consider young people aged 15 to 29 (WHO, 2015); In 94% of the cases, the fault did not lie with the vehicle but with the human drivers, be it drunkenness, drowsiness or distraction (NHTSA, 2015); Sadly, even though the price paid every year is too high, the number of casualties is expected to rise as a result to more people embracing car ownership (Lipson and Kurman, 2016).

Supporters of a rapid adoption and quick mainstreaming of autonomous cars believe that their benefits far outweigh their disadvantages; these beliefs are far from baseless as many facts seem to support them; for instance, according to the Eno Center for Transportation (Eno), if 90% of the driven cars in the USA were autonomous "the number of driving related deaths would fall from 32400 per year to 11300" (Eno, 2013); Other major benefits of autonomous cars are their convenience, ease of use and the freedom they offer to consumers, especially to the old, disabled and those incapable of driving.

However, benefits of autonomous cars notwithstanding, they are far from being perfect or at the very least they present many issues that make it hard for consumers to accept them wholeheartedly. In fact many are reluctant to use them for a multitude of reasons; some do not trust them to be safe, secure or private, others avoid them because of social pressure and some consumers have trouble accepting them simply because they love driving.

In order to have a deep understanding of the drivers and inhibitors governing the consumers' attitudes towards autonomous cars' acceptance, we investigated the main probable drivers; the proposed research model comprises constructs from UTAUT2 as well as other relevant constructs that are rooted in the literature and strongly relevant to the context of this research.

2 Theoretical Background and Hypotheses

Technology acceptance models have been around since the early days of information system research, their aim –unchanging over the years- is to investigate the factors influencing the adoption of a technology or its rejection; Several such models emerged over time: TRA (1975), TPB (1985), TAM (1989) and UTAUT (2003) to mention some of them (Venkatesh et al., 2003). UTAUT2, an extended version of UTAUT proposed by Venkatesh in 2012, presents a fitting basis for our present research; some of its constructs, pertaining to usefulness (Performance Expectancy), ease of use (Effort Expectancy), social pressure (Social influence) and enjoyment (Hedonic Motivation), should play a major role considering the nature of the present research (Venkatesh, Thong and Xu, 2012). Certainly, the next step is to adapt the theory to the current context; Hong et al (2014) clearly defined the approaches for the contextualization of a theory (Hong et al., 2014); the first level of this process is to add or remove core constructs; Next, contextual factors such as antecedents are incorporated in the model. Following these guidelines we assimilated some key constructs –rooted in the literature- into the model (see figure 1); these constructs are Desirability of Control (DEC) defined as "the fear of losing control over the vehicle" (Planing, 2014), Perceived Convenience (PC) which is "the level of convenience toward time, place and execution that one feels when driving an autonomous car" (Hsu and Chang, 2013), Personal Innovativeness in IT (PIIT) defined as an "individual trait reflecting a willingness to try out any new technology" (Agarwal and Prasad, 1998) and the Intention to Prefer an autonomous car over a conventional car (IP). The hypotheses regarding the influence of the previously mentioned constructs on the Behavioral Intention (BI), i.e. the intention of the consumer to use fully autonomous cars, are the following:

H1: PIIT has a positive influence on BI

H1: DEC has a negative influence on BI

H3: HM has a positive influence on BI

H4: PE has a positive influence on BI

H5: EE has a positive influence on BI

H6: SI has a positive influence on BI

H7: PC has a positive influence on BI

H8: BI has a positive influence on IP

Additionally, risks are expected to play a major role inhibiting the acceptance of autonomous cars. we singled out five relevant types of risks, these risks are (1) Privacy Risk (PRIV) linked to a "possible loss of privacy as a result of a voluntary or surreptitious information disclosure to the autonomous car" (Dinev and Hart, 2006; Liao, Liu and Chen, 2011), (2) Performance Risk (PERR) associated with "The

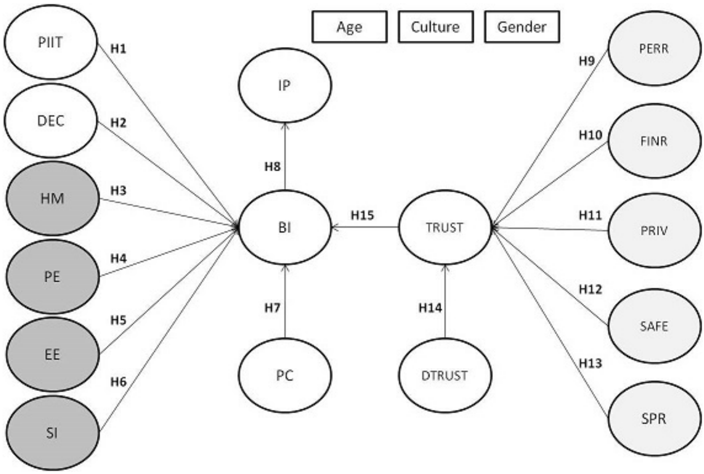

Figure 1: Proposed research model

possibility of the autonomous car malfunctioning and not performing as it was designed and advertised and therefore failing to deliver the desired benefits." (Grewal, Gotlieb and Marmorstein, 1994), (3) Safety Risk (SAFE) which is the risk of the user's safety being endangered through his use of an autonomous car, (4) Financial Risk (FINR) pertaining to "the potential monetary outlay associated with the initial purchase price as well as the subsequent maintenance cost of autonomous cars" and finally (5) Socio-psychological Risk (SPR) defined as the "Potential loss of status in one's social group as a result of using fully autonomous cars, looking foolish or untrendy and risking to lower the consumer's self image" (Kim, Lee and Jung, 2005). Understanding the influence risks have on trust is a major point in this research as it will not only show which risks are relevant but also which ones have more impact. Trust (TRUST) is defined by Mayer et al. (2011) as "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the truster, irrespective of the ability to monitor or control that other party". We believe the disposition of a person to trust might also play a role in him/her trusting autonomous cars, hence the DTRUST construct, defined as "how a person sees himself/herself in regards to his/her interactions with other people"(Srivastava, Singh and Srivastava, 2013).

The hypotheses pertaining to trust are the following:

H9: PERR has a negative influence on TRUST

H10: FINR has a negative influence on TRUST

H11: PRIV has a negative influence on TRUST

H12: SAFE has a negative influence on TRUST

H13: SPR has negative influence on TRUST

H14: DTRUST has a positive influence on TRUST

H15: TRUST has a positive influence on BI

3 Methodology

3.1 Sample Description

An online study was conducted in Germany and the USA to collect the necessary data for the present study. The questionnaire was designed following the well-established principles for survey design by Dillman, Tortora and Bowker (1998). The survey took approximately 10 minutes to complete and was accessible for three weeks starting from May 31st, 2017.

313 participants answered the survey of which 160 reside in the USA and 153 in Germany. The survey was designed in a way that participants had to answer all questions before they were able to submit the questionnaire.

Age distribution shows the mean age of the respondents to be 35; it also shows 41.9% of them to be male and 58.1% to be female (see table 1).

The majority of the participants have an annual income inferior to €50.000. 95.5% of the respondents have had some experience driving cars and 84.3% of them currently own one.

Table 1: Participant demographics

Variable	Category	Freq	In%	Mode
Gender	Male	131	41.9	Female
	Female	182	58.1	
Age	Younger than 35	175	55,9	29
	35 and older	138	44.1	
Education	8th grade or less	2	0.6	Graduated from college, graduate or post-graduate school
	Some high school (Grade 9-11)	14	4.5	
	Graduated from high school	81	25.9	
	1-3 years of college/university	74	23.6	
	Graduate or postgraduate	138	44.1	
	No answer	1	0.3	
Annual Income	Less than €50.000	157	50.2	Less than €50.000
	€50.000 to €100.000	88	28.1	
	€100.000 to €150.000	14	4.5	
	€150.000 and more	3	1	
	I would rather not say	51	16.3	
Car Owner- ship	Yes	264	84.3	Yes
	No	49	15.7	
Driving Experience	Yes	299	95.5	Yes
	No	14	4.5	

3.2 Data Analysis

For the purpose of data analysis, we opted for the PLS SEM approach. PLS SEM also known as PLS Path Modeling presents a good choice when the purpose of the study is prediction rather than confirmation and when the analyzed samples are small (Reinartz, Haenlein and Henseler, 2009). There are two parts to PLS SEM; the first part is where the measurement (outer) model is assessed to determine its reliability and validity. The structural (inner) model assessment is performed in the second part of the analysis, the aim of which is to determine the significance of the paths and R^2 values (Anderson and Gerbing, 1988). For the purpose of this analysis SmartPLS 3.0 Professional was used.

3.3 Measures

All questionnaire items were measured on a seven-point Likert scale ranging from "strongly disagree" to "strongly agree". The DEC, HM, SI, BI, DTRUST, PRIV and SPR constructs were measured with three items; EE, PE, TRUST, PERR and FINR with two items each, SAFE was the only construct measured with four indicators and IP was the only single item construct in the model.

4 Results

4.1 Assessment of the Reliability and the Validity of the Measurement Model

First we examine the indicators' reliability, according to Chin (1998) and Hulland (1999) indicator reliability is established if each indicator presents a loading value of 0.70 or higher. Our results demonstrated that the items' loadings were generally satisfactory.

Next, internal consistency reliability is in turn assessed, Hair et al. (2014) advise to use composite reliability (CR) as a measure for it; a CR of 0.70 or higher is generally regarded as acceptable for research (Bagozzi and Yi, 1988; Chin, 2010; Henseler, Ringle and Sinkovics, 2009; Vinzi, Trinchera and Amato, 2010); our results fully satisfy the required threshold as all estimated values were recorded to be higher than 0.70 (see table 2).

As a result to the first two assessments, the models' reliability is established. Turning to convergent validity, we assessed the AVE values for all our datasets; the values we registered were all higher than 0.50, which is the required threshold for this measure.

Finally, we used the Heterotrait-Monotrait Ratio of Correlations (HTMT) criterion (see table 3) to detect possible discriminant validity issues in the model. According to Hair et al. (2014) HTMT values lower than 0.90 signify the model to be clear of such issues; this condition is fulfilled in all datasets as shown in table 3, hence, discriminant validity is satisfied.

Table 2: Assessment results of the measurement model

Construct	Item	Loading	CR	AVE
BI	Bi1	0.95	0.96	0.89
	Bi2	0.94		
	Bi3	0.94		
DEC	Dec1	0.88	0.84	0.63
	Dec2	0.66		
	Dec3	0.83		
DTRUST	Dtrust1	0.86	0.89	0.73
	Dtrust2	0.87		
	Dtrust3	0.83		
EE	Ee1	0.91	0.91	0.84
	Ee2	0.92		
FINR	Finr1	0.78	0.86	0.76
	Finr2	0.95		
HM	Hm1	0.93	0.95	0.86
	Hm2	0.94		
	Hm3	0.91		
PC	Pc1	0.91	0.93	0.86
	Pc2	0.95		

Continued on next page

Table 2 – continued from previous page

Construct	Item	Loading	CR	AVE
PE	Pe1	0.91	0.92	0.86
	Pe2	0.95		
IP	Ip1	1.00	1.00	1.00
PERR	Perr1	0.87	0.89	0.81
	Perr2	0.93		
PIIT	Piit1	0.92	0.92	0.84
	Piit2	0.92		
PRIV	Priv1	0.87	0.94	0.84
	Priv2	0.95		
	Priv3	0.93		
SAFE	Safe1	0.87	0.90	0.68
	Safe2	0.88		
	Safe3	0.77		
	Safe4	0.78		
SI	Si1	0.93	0.96	0.89
	Si2	0.96		
	Si3	0.94		
SPR	Spr1	0.69	0.84	0.64
	Spr2	0.81		
	Spr3	0.89		
TRUST	Trust1	0.90	0.85	0.74
	Trust2	0.82		

Table 3: Discriminant validity assessment – HTMT

	DEC	DTRUST	EE	FINR	HM	IP	PC	PE	PERR	PIIT	PRIV	SAFE	SI	SPR	TRUST
SPR															0.08
SI														0.37	0.50
SAFE													0.19	0.08	0.51
PRIV												0.62	0.05	0.12	0.25
PIIT											0.12	0.18	0.31	0.23	0.61
PERR										0.24	0.36	0.72	0.20	0.31	0.57
PE									0.31	0.39	0.04	0.19	0.42	0.07	0.67
PC								0.76	0.41	0.33	0.06	0.19	0.36	0.09	0.60
IP							0.59	0.61	0.53	0.41	0.17	0.40	0.52	0.15	0.67
HM						0.62	0.62	0.60	0.36	0.38	0.11	0.25	0.44	0.16	0.67
FINR					0.20	0.37	0.31	0.17	0.65	0.24	0.28	0.71	0.26	0.21	0.41
EE				0.33	0.58	0.63	0.69	0.74	0.46	0.44	0.14	0.34	0.39	0.05	0.76
DTRUST			0.30	0.20	0.24	0.20	0.18	0.23	0.14	0.40	0.10	0.14	0.31	0.09	0.46
DEC		0.09	0.42	0.56	0.34	0.63	0.42	0.34	0.69	0.16	0.35	0.64	0.19	0.11	0.41
BI	0.51	0.33	0.70	0.47	0.69	0.83	0.63	0.62	0.55	0.58	0.19	0.42	0.60	0.14	0.80

4.2 Assessment of the Reliability and the Validity of the Structural Model

Moving on to the assessment of the validity and reliability of the structural model, first and foremost, we assessed the Variance Inflation Factor (VIF); our findings were that all VIF estimates were smaller than 5; indicating the absence of collinearity issues.

Next, we assessed the significance of path coefficients by calculating t-values; we performed a bootstrapping procedure and used the settings recommended by Hair et al. (2014) (5000 bootstraps, two-tailed tests). The significance thresholds for the t-values are 2.58 for 99% confidence level, 1.96 for 95% confidence level and 1.75 for a 90% confidence level (Hair et al. 2014).

The results of our analysis (displayed in figure 2) show that $PIIT > BI, DEC > BI$, $HM > BI$, $SI > BI$, $EE > BI, TRUST > BI$, $DTRUST > TRUST, FINR > TRUST, PERR > TRUST$ and $BI > IP$ are significant at 99% confidence level (t-value > 2.58); they also show $SAFE > TRUST$ to be significant at 95% confidence level (t-value > 1.96) and SPR $>$ TRUST at 90% confidence level (t-value > 1.75). The relationships that did not satisfy the minimum requirements for significance were $PE > BI$, $PC > BI$, FINR $>$ TRUST and PRIV $>$ TRUST. As a result Hypotheses H4, H7, H10 and H11 are rejected.

The results for the R^2 calculations (displayed in table 4) show that all endogenous variables are well explained by their relationships. The highest R^2 was estimated at 0.71 for BI, followed by IP (0.64) and finally TRUST (0.32). In the field of consumer behavior, a R^2 of 0.20 is usually regarded as high (Hair, Ringle and Sarstedt, 2011; Hair et al., 2014).

In order to perform a group moderation, we used the Multi Group Analysis algorithm available in Smartpls3.0; it allowed us to have an better understanding of whether people of different cultures (USA and Germany), ages ($<$=35 and $>$35) and genders (male and female) would approach autonomous cars‘ acceptance differently, the results are visible in table 4.

Gender and culture were found to play an active role as moderators contrary to age. Our results show that women are more likely to prefer using an autonomous car if they choose to use it; they also show women to be more influenced by their social environment than men; these latter’s dispositions to trust were found to play a more active role in them trusting autonomous cars. In regards to culture as

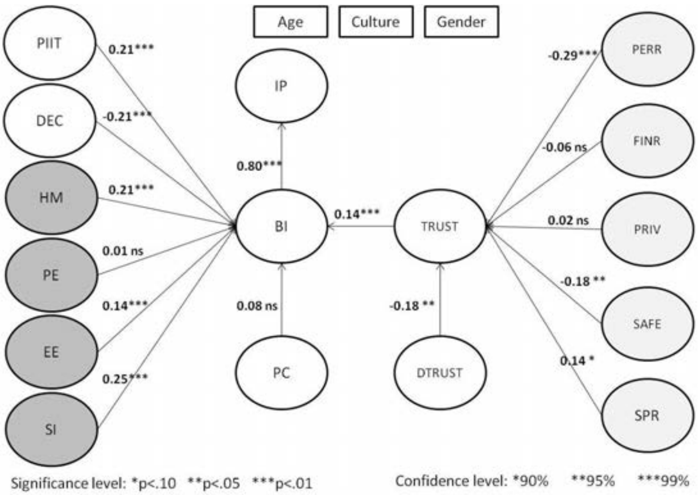

Figure 2: Path coefficients and significance level of the relationships

Table 4: Group moderation - results of the parametric test

Path/Moderator	Gender	Age	Country
BI ->IP	2.03**	0.78	0.29
DEC ->BI	0.63	1.39	0.29
DTRUST ->TRUST	2.24**	0.99	0.70
EE ->BI	1.06	1.14	0.10
FINR ->TRUST	1.65	0.18	0.49
HM ->BI	1.94*	0.27	0.82
PC ->BI	0.33	1.02	0.00
PE ->BI	0.53	0.82	0.33
PERR ->TRUST	0.55	0.96	0.47
PIIT ->BI	0.59	0.07	0.34
PRIV ->TRUST	0.4	0.29	1.36
SAFE ->TRUST	0.34	0.06	0.74
SI ->BI	2.24**	0.12	0.81
SPR ->TRUST	1.22	1.55	2.59***
TRUST ->BI	0.49	0.53	0.25

Significance level: *p<.10 **p<.05 ***p<.01 Confidence level: *90% **95% ***99%

a moderator, findings show that socio-psychological risks are strong in Germany contrary to the USA where they were found to be insignificant.

It is worth noting that in regards to effect sizes (f^2 values), a strong effect size was recorded for BI $>$ IP (1.79); SI $>$ BI (0.17) had the only registered medium effect and all the remaining effects were small, with the exception of FINR $>$ TRUST, PC $>$ BI, PE $>$ BI and PRIV $>$ TRUST (the rejected hypotheses) where the recorded effect sizes were inferior to 0.02 and therefore deemed insignificant.

5 Discussion and Conclusion

The main aim of this study was to identify the drivers and inhibitors governing the consumer‘s behavior in regards to the acceptance of fully autonomous cars.

For that purpose, we conducted an online survey in two countries namely Germany and the USA; the collected data was then analyzed using PLS SEM. The results of the analysis shed light on the main drivers influencing consumers' intention to use fully autonomous cars; they also allowed to gauge the role these drivers play in terms of impact.

Our findings showed that many factors positively influence the user's intention to use an autonomous car; and while some of these factors are related to the technology itself such as it being "easily used" or "enjoyable", others are associated with the user's own personality such as "personal innovativeness" or the influence of the environment on him/her; The key inhibitors to autonomous cars' acceptance were found to be the consumers' thirst for control and risks; Some risks were recorded to have a great influence on a consumer trusting a car, these risks are: the risk of the car being unsafe and the risk of the car malfunctioning. Surprisingly, the performance expectancy of the autonomous cars as well as their convenience were found not to be significant, this can be explained as consumers being more influenced by the negative aspect i.e. the car malfunctioning as well as the unavailability of the car in the market at the present time. Risks that were ascertained to be extraneous are the financial risk as well as the privacy risk as many people did not find them to be "deal breakers".

In terms of implications for theory, the contributed research model comprises all the key elements that play a major role in the acceptance or rejection of fully autonomous cars; as such it can be used in future research as a reference for a contextualized model of technology acceptance in the automobile industry. In terms of managerial and practical implications, the current study presented findings that clarified which elements have an impact -and to which level- making it easier for stakeholders to make a better advised decision when dealing the inhibitors to the acceptance of autonomous cars or when promoting the attractive qualities of these vehicles. Advertizing the benefits of the car should help people have a better understanding of what to expect in terms of productivity and comfort. Decision makers should find ways to promote trust in fully autonomous vehicles, and that through dealing with the consumer concerns' linked to the performance of the car and to the safety of the user, as these were found to be the strongest inhibiting risk factors; they should also find ways to soften and implicate the people who prefer to have constant control while commuting. Findings related to gender, culture and personal innovativeness should ultimately help devise improved strategies to target these specific population segments in a more effective way.

References

Agarwal, R. and J. Prasad (1998). "A Conceptual and Operational Definition of Personal Innovativeness in the Domain of Information Technology". In: *Info. Sys. Research* 9.2, pp. 204–215.

Anderson, J. C. and D. W. Gerbing (1988). "Structural equation modeling in practice: A review and recommended two-step approach." In: *Psychological bulletin* 103.3, p. 411.

Bagozzi, R. P. and Y. Yi (1988). "On the evaluation of structural equation models". In: *Journal of the academy of marketing science* 16.1, pp. 74–94.

Chin, W. W. (1998). "The partial least squares approach for structural equation modeling." In: George A. Marcoulides. Chap. 10, pp. 295–336.

Chin, W. W. (2010). "How to Write Up and Report PLS Analyses". en. In: *Handbook of Partial Least Squares*. Ed. by V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang. Springer Handbooks of Computational Statistics. Springer Berlin Heidelberg, pp. 655–690.

Dillman, D. A., R. D. Tortora, and D. Bowker (1998). "Principles for constructing web surveys". In: *Joint Meetings of the American Statistical Association*.

Dinev, T. and P. Hart (2006). "An Extended Privacy Calculus Model for E-Commerce Transactions". en. In: *Information Systems Research* 17.1, pp. 61–80.

Eno (2013). *Preparing a Nation for Autonomous Vehicles*. Tech. rep.

Grewal, D., J. Gotlieb, and H. Marmorstein (1994). "The Moderating Effects of Message Framing and Source Credibility on the Price-Perceived Risk Relationship". en. In: *Journal of Consumer Research* 21.1, p. 145.

Hair, J. F., C. M. Ringle, and M. Sarstedt (2011). "PLS-SEM: Indeed a Silver Bullet". In: *The Journal of Marketing Theory and Practice* 19.2, pp. 139–152.

Hair, J. F., G. T. M. Hult, C. Ringle, and M. Sarstedt (2014). *A primer on partial least squares structural equations modeling (PLS-SEM)*. English. Los Angeles: SAGE.

Hair, J. F., M. Sarstedt, L. Hopkins, and V. G. Kuppelwieser (2014). “Partial least squares structural equation modeling (PLS-SEM): An emerging tool in business research”. en. In: *European Business Review* 26.2, pp. 106–121.

Henseler, J., C. M. Ringle, and R. R. Sinkovics (2009). “Advances in International Marketing”. en. In: Advances in International Marketing 20. Ed. by J. Henseler, C. M. Ringle, and R. R. Sinkovics.

Hong, W., F. K. Y. Chan, J. Y. L. Thong, L. C. Chasalow, and G. Dhillon (2014). “A Framework and Guidelines for Context-Specific Theorizing in Information Systems Research”. en. In: *Information Systems Research* 25.1, pp. 111–136.

Hsu, H.-h. and Y.-y. Chang (2013). “Extended TAM Model: Impacts of Convenience on Acceptance and Use of Moodle.” In: *Online Submission* 3.4, pp. 211–218.

Hulland, J. (1999). “Use of partial least squares (PLS) in strategic management research: a review of four recent studies”. en. In: *Strategic Management Journal* 20.2, pp. 195–204.

Kim, H. K., M. Lee, and M. Jung (2005). “Perceived Risk and Risk-Reduction Strategies For High-Technology Services”. In: 6, pp. 171–179.

Liao, C., C.-C. Liu, and K. Chen (2011). “Examining the impact of privacy, trust and risk perceptions beyond monetary transactions: An integrated model”. en. In: *Electronic Commerce Research and Applications* 10.6, pp. 702–715.

Lipson, H. and M. Kurman (2016). *Driverless: intelligent cars and the road ahead*. Cambridge, Massachusetts: The MIT Press.

Mayer, P., D. Volland, F. Thiesse, and E. Fleisch (2011). “User Acceptance of’Smart Products’: An Empirical Investigation”. In:

NHTSA (2015). *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey.pdf*. Tech. rep. NHTSA’s National Center for Statistics and Analysis.

Planing, P. (2014). *Innovation Acceptance*. en. DOI: 10.1007/978-3-658-05005-4. Wiesbaden: Springer Fachmedien Wiesbaden.

Reinartz, W., M. Haenlein, and J. Henseler (2009). “An empirical comparison of the efficacy of covariance-based and variance-based SEM”. en. In: *International Journal of Research in Marketing* 26.4, pp. 332–344.

Srivastava, R. K., S. Singh, and V. Srivastava (2013). “The Role of Trust and Technology Acceptance Model(TAM) on Customer Acceptance of Mobile Banking: An Integrated Model to Improve Mobile Banking in Banking Sector-A Conceptual Paper”. en. In: *International Journal of Asian Business and Information Management* 4.1, pp. 31–43.

Venkatesh, V., M. G. Morris, G. B. Davis, and F. D. Davis (2003). “User acceptance of information technology: Toward a unified view”. In: *MIS quarterly*, pp. 425–478.

Venkatesh, V., J. Y. Thong, and X. Xu (2012). “Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology”. In: *MIS quarterly* 36.1, pp. 157–178.

Vinzi, V. E., L. Trinchera, and S. Amato (2010). “PLS Path Modeling: From Foundations to Recent Developments and Open Issues for Model Assessment and Improvement”. en. In: *Handbook of Partial Least Squares*. Ed. by V. E. Vinzi, W. W. Chin, J. Henseler, and H. Wang. Springer Handbooks of Computational Statistics. Springer Berlin Heidelberg, pp. 47–82.

WHO (2015). *Global status report on road safety 2015*. English. OCLC: 985423312.

Data Source Taxonomy for Supply Network Structure Visibility

Johannes Zrenner[1], Ahmad Pajam Hassan[2], Boris Otto[1], Jorge Marx Gómez[2]

1 – Technical University of Dortmund

2 – Carl von Ossietzky University of Oldenburg

The supply network structure of manufacturers is complex and non-transparent. In order to achieve a higher visibility and consequently increase the performance, the existing lack of data has to be closed. This paper answers the questions, how to identify, describe and compare suitable data sources for an end-to-end visibility. Following the design science research process, two artifacts are developed based on conceptual-to-empirical approaches. The initial conceptualizations result from literature reviews. The conceptual representation of supply network structure data sources clarifies the relevant data entities and attributes. It supports the identification process of relevant data sources. The data source taxonomy (i.e. classification scheme) describes data sources using fourteen dimensions and up to four potential characteristics. It assists a standardized description. Both artifacts are demonstrated in case studies with German automotive Original Equipment Manufacturers. The findings add to the knowledge base of supply network visibility with a focus on the network structure. A large part of the existing literature about supply chain visibility is too vague on the data perspective. Therefore, this paper closes an important gap regarding the supply chain digitalization by introducing two applicable results, which enable a new course of action for practitioners and researchers.

Keywords: Data Source Taxonomy; Supply Chain Visibility; Supply Network Structure; Design Science Research

1 Introduction

In the age of globalization, cost pressure and the customizing requirement, companies are constrained to be focused on their main capabilities. Therefore, make or buy decisions are followed by outsourcing business processes, which makes supply networks more complex and dynamic (Tang and Tomlin, 2008). For handling the dynamic of supply networks and reduce the uncertainty, it is necessary to make supply network relations visible (Christopher and Lee, 2004). Thus, visibility becomes a key topic in Supply Chain Management research (Yu, Yan and Edwin Cheng, 2001). With more visibility in supply chains, the performance improves (Pidun and Felden, 2012) and decision making processes get supported (Kulp, Lee and Ofek, 2004).

From the perspective of a manufacturer, visibility of all supply network members is only given for the first tier supplier (Basole and Bellamy, 2014), because of direct business relationships. Data about them is internally stored in databases. After the first tier supplier, the upstream supply chain gets increasingly unknown (Christopher and Lee, 2004). Missing interconnections between data silos among business areas, supply chain members and other external data sources are the reason for the lack of end-to-end visibility. This issue can be solved by linking disparate data sources. The various available data sources are highly heterogeneous, own different characteristics and contents (Rozados and Tjahjono, 2014). For that reasons, it is difficult to identify and select the suitable data sources for linking processes. Furthermore, a general understanding of the data sources is missing, which is needed to negotiate about data source sharing with supply chain members. For example, potential data sources are owned by a first tier supplier, logistics contractors or data providers.

The goal of this paper is to enhance the knowledge about data sources for supply network structures and thus support linking processes for practitioners and researchers. According to that, the first research question (RQ) addresses a general data model, which helps to identify data sources with a suitable content. The data model clarifies the entities and attributes, a data source about the supply network structure has. The first research question is:

RQ1: How does a conceptual representation for supply network structure data sources look like?

Following the identification of available data sources, a comparison has to be conducted. The goal is to find out, which are the most suitable data sources from an effort-benefit point of view, for bridging data lacks within the supply network. For that reason, a taxonomy (i.e. classification scheme) is needed, which standardizes the description of the data sources and makes them comparable. Accordingly, the second research question is:

RQ2: How does a taxonomy of data sources for supply network structures look like?

This investigation contributes to the research of information systems. It follows the design science research (DSR) process from Peffer et al. (2007). It is an iterative research and design process. The process combines scientific and practitioner's knowledge for designing the artifact.

The remainder of the paper is structured as follows. Section 2 lays out the related work of concepts for supply chains and data source taxonomies. Section 3 presents a conceptual representation for supply network structure data sources. In section 4 the data source taxonomy is established. Section 5 describes the application of the conceptual representation and the taxonomy. Section 6 demonstrates the conceptual representation and the taxonomy through two case studies with German Original Equipment Manufacturers (OEMs). Section 7 summarizes the contributions to research and practice as well as showing fields for future research.

2 Related Work

2.1 Concepts for Supply Chains

Supply Chain Management is focused on managing the whole supply chain from the raw material producer to the end customer (Harland, 1996). The intentions of supply chain integration are improvements on performance and operational figures (Ramdas and Spekman, 2000; Frohlich and Westbrook, 2001; Rosenzweig, Roth and Dean, 2003; Cagliano, Caniato and Spina, 2004).

This investigation addresses the supply network from n-tier supplier to its Original Equipment Manufacturer in a different way from most other researches. They are focused on processing data from the interaction between supply network members (Levary, 2000; Zhao, Xie and Zhang, 2002) and data sharing (Bowersox, Stank and Closs, 2000). The object of this investigation is to analyze different data sources about business relations in a manner, that it can be used for increasing the visibility of supply network structures. In this context, Mukaddes et al. (2010) propose a conceptual information model for Supply Chain Management and integration. The model deals with the integration of supply chain members and focuses on the flow of information between the chain members. Grubic and Fan (2010) present a study of state-of-the-art research in supply chain ontology. They identify outstanding research gaps and six supply chain ontology models are identified from a systematic review of literature. In the context of decision support in global supply chain, Wang, Wong and Fan (2013) build an ontology for steel manufactures, which represent eleven main classes and the associated attributes.

Despite existing contributions, there remains a need to specify a dedicated ontology as a model for conceptualizing supply network structure data sources.

2.2 Data Source Taxonomies

In the generation of big data, there are a lot of data sources relevant for Supply Chain Management. Leveling, Edelbrock and Otto(2014) propose an overarching model of data categorization. It classifies data in nucleus data, community data and open big data. For this, the following characteristics are considered: fuzziness, volume and change frequency.

A review from Rozados and Tjahjono (2014) identifies 52 data sources and classifies them to a taxonomy. The main characteristics for this classification are volume, velocity and variety. The characteristic variety is divided into structured data, semi-structured data and unstructured data. For example, core transactional data like transportation costs, origin and destination are structured data with small volume and velocity. Semi or unstructured data like weather data or machine-generated data have a high volume and velocity.

Otto, Abraham and Schlosser (2014) propose a morphology, which makes the relevant characteristics of the data resource in networked industries transparent. The morphology is based on four case studies and has eleven dimensions with two to six characteristics. Even though this morphology is pretty detailed, it is specific to the data resource. Data resources entail all databases in a company.

Given this scarce knowledge base about data source taxonomies, there is a clear need to investigate this topic further.

3 Conceptual Representation of Supply Network Structure Data Sources

Since there is no common standard for the vision of an integrated supply network through data flow integration (Loh, Koh and Simpson, 2006; Patnayakuni, Rai and Seth, 2006), it is necessary to find new approaches to make the supply network structure visible. For this purpose, the first step is to define the relevant aspects of supply network structure data sources. Therefore, a conceptual representation based on domain specific literature is developed. The authors identify relevant literature, extract fundamental supply network data features and create an entity relationship model following the framework of Chen (1976). By space limitations, only the most relevant components of the model are explained in detail.

"The membership in a network and its organization vary for a given product and over time" (Choi and Hong, 2002), the attribute "valid time" is considering this fact and makes relations time sensitive. It is assigned to the relation "deliver" and "demand". In respect to the data and product flow, it is also necessary to differentiate between several kinds of functional areas within an organization and between supply network member organizations (Basole and Bellamy, 2014). Following that, the entity company owns an attribute representing the type of location. Examples for locations types are supplier, manufacturer, warehouse, distributor and retailer. Moreover, to the entity transferred product an attribute is assigned, which classifies its type, for example raw material, parts and components. Companies within a supply chain are using applications which are based on different ontologies. That leads to inconsistent terms and semantics which have a negative influence on the interoperability for supply chain integration (Ye, et al., 2008). According to the eCl@ss standard (eCl@ss, 2017), the entity product could own different designations, for example identifier, preferred name or short name. Those designations could even differ between languages. Considering the variety in semantics, both entities "product" and "company" own an "alias" feature. This feature makes it possible to express different semantics, which are used by their data source.

Figure 1 shows the designed representation. It provides the relevant aspects of supply network structure data sources in a formal way. Furthermore, it is used in the taxonomy application (section 5) to identify potential data sources.

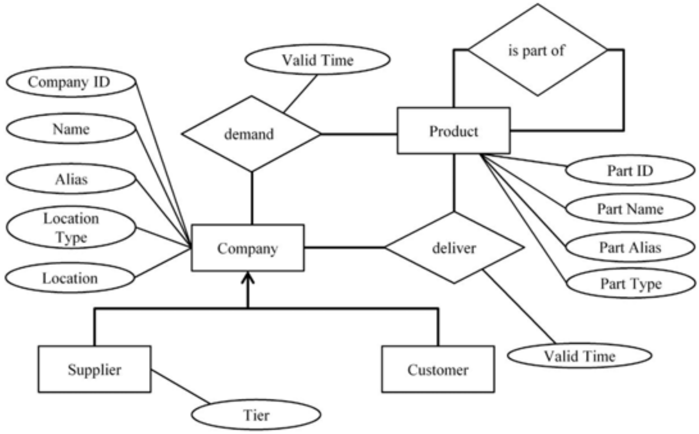

Figure 1: Conceptual representation of supply network structure data sources

4 Data Source Taxonomy

4.1 Background

A taxonomy is a classification scheme of objects from a specific research area. It supports scientists and practitioners to understand and analyze complex domains (Nickerson, Varshney and Muntermann, 2013). A morphological box structures the identified dimensions and characteristics of the investigated objects. Therefore, the morphological box is a suitable presentation of a taxonomy.

For the taxonomy development in information systems, Nickerson et al. (2013) propose a method with two different approaches. The empirical-to-conceptual approach starts with identifying a subset of objects and determining the characteristics. After that, the characteristics are grouped into dimensions and the taxonomy is created. The first step of the conceptual-to-empirical approach is the conceptualization of the characteristics and dimensions. Step two is about the examination of objects with these characteristics and dimensions. The third step is to create the taxonomy.

4.2 Taxonomy Development Process

The authors follow the method of Nickerson et al. (2013) and choose the conceptual-to-empirical approach. For researchers with significant knowledge about the domain, it is the recommended approach (Nickerson, Varshney and Muntermann, 2013). The initial conceptualization of the dimensions and characteristics is based on the researcher notions about data sources as well as a review of the literature. The authors scour scientific databases (IEEE Xplore, Web of Science, ACM DL, Emerald Insights, ScienceDirect) for the following search terms: “data taxonomy”, “big data in Supply Chain Management” and “Supply Chain Visibility”. Two demonstration iterations in a business environment (section 6) are used to examine data sources with the identified dimensions and characteristics.

The results of the described process lead to the taxonomy of data sources for supply network structures (figure 2).

Dimension	Characteristics			
Data Source Availability	Internal	External – Closed		External – Open
Data Source Interface	Internal Interconnection	Traditional EDI	Web Services	Offline Data Dump
Data Source Pricing Model	Volume-Driven	Time-Driven	Unique	No
Data Aggregation	Resource	Database	Record	Item
Data Occurrence/Update	Stream	Event-Driven Batch		Time-Driven Batch
Data Ownership	One Legal Entity	Community		Public
Data Structure	Structured	Semi-Structured		Unstructured
Data Format	Proprietary		Open	
Intra Data Standardization	Value	Semantic	Syntax	No
Inter Data Standardization	Value	Semantic	Syntax	No
Data Currency	Forecast	Up-To-Date		Outdated
Data Completeness	High	Medium		Low
Data Accuracy	High	Medium		Low
Data Sharing	Proprietary	Free		Open

Figure 2: Taxonomy of Data Sources

4.3 Taxonomy Details

Each of the fourteen dimensions has two to four potential characteristics, which are not exclusive but listed in the same row. That means, one dimension can have one or more applying characteristics.

Data Source Availability: If a data source is internal or external, is the main differentiation between data sources. From an enterprise perspective, an internal data source is available in the company's IT infrastructure for example, a database of the ERP system. External data sources are not available in the company's IT infrastructure and can be divided into closed and open data. The difference is the charged or free access to the data source. When the data has to be either purchased or licensed, the data source is called closed (Leveling, Edelbrock and Otto, 2014). Open Data is freely available on the public internet and can be used without technical, financial or legal barriers (Murray-Rust, et al., 2010).

Data Source Interface: For end-to-end visibility of supply network structures, data from different sources has to be accessible from a single point of access. Therefore, an interconnection of data sources is required. Internally available data sources can be distributed across business areas (Rozados and Tjahjono, 2014) and thus an internal interconnection is sufficient. Between the OEM and the supplier normally exists a traditional Electronic Data Interchange (EDI) connection for transactional data (Zilbert, 2000), which can be the connection for those kinds of external sources. Web Services are a cross-platform way to connect external data sources (Li, Sun and Tian, 2015) from a supplier, data provider, or Open Data. A Data dump is a snapshot of data and is often used when IT infrastructure is limited for a single or prototypical data transfer, like for example an Excel file sent by email.

Data Source Pricing Model: For each of the four used characteristics, one example of a potential supply network structure data source is named. The pricing model from Achilles (2017) is based on the number of used product codes. Therefore, Achilles is an example for a volume-driven pricing model. Panjivia (2017) has a time-driven model with a monthly and annually option. IHS (2014) offers reports for a unique payment. When linking data sources within a division of a company, normally no pricing model is used.

Data Aggregation: Data aggregation describes the aggregation level of the data source. An instantiation of an attribute of a data object is called data item. A data record is the instantiation of a data object. Data records constitute database tables.

The highest level of aggregation is data resource. The data resource includes all databases of a company (Otto, Abraham and Schlosser, 2014).

Data Occurrence/Updates: Data occurrence is distinguished in batches and streams. Examples for streams are the social media streams or the shop-floor data streams (Otto, Abraham and Schlosser, 2014). Batches are sets of data records and no continuous data flow like streams. Therefore, data updates are usually for batches. There can be an event or time-driven trigger for updates.

Data Ownership: If data is a private good, it is owned by a legal entity like a company. Data as a club good is owned by a community and public data goods like addresses are available for the public (Otto, Abraham and Schlosser, 2014).

Data Structure: Data without an identifiable structure or a data model is called unstructured data. For example, photos or narrative text are unstructured data (Kubler, et al., 2015). Semi-structured data like XML or machine-generated log files have an irregular and flexible structure, but cannot be processed in relational databases efficiently. However, ERP transaction data or origination and destination are structured data and can be straightforwardly transferred to a relational database (Rozados and Tjahjono, 2014).

Data Format: Open data formats, such as HTML, XML, JSON, RDF or CSV can be used by anyone, unlike proprietary formats. Binary data from machine to machine communication is one example for proprietary formats (Kubler, et al., 2015). PDF or DOC are other common proprietary data formats.

Data Standardization: Data can be standardized on the syntactic level, on the semantic level and on value level. Standardization on a value level standardizes the possible values of a data item (Otto, Abraham and Schlosser, 2014). Semantic heterogeneity through homonyms or synonyms leads to different meanings or interpretation problems. A homonym denotes different terms and a synonym denotes the same term as another notation (Bergamaschi, et al., 2011). The demonstration of the taxonomy (section 6) leads to additional characteristics. If the data source is not standardized at any level, the characteristics "No" is necessary. Moreover, the demonstration results lead to a differentiation between "Intra Data Standardization" and "Inter Data Standardization". Intra refers to the standardization inside of a data source. On which level the standardization of the data fits from one data source to other ones, is covered by "Inter Data Standardization".

Data Quality and Data Value: Data quality is essential for data analytics because the accuracy of the analytics methods depends on the data which they are based on. That means the results can only be as good as the input data. The intrinsic data quality dimensions are (Hazen, et al., 2014):

— Accuracy: Does the data equivalent to their corresponding real values?

— Timeliness: Currency (length of time since the record's last update) and Volatility (frequency of updates)

— Consistency: Matches the data regarding format and structure?

— Completeness: Is the data complete or is there data missing?

Extended literature considers the value of information and neglects the value of data. Data is used to generate information and therefore scholars do not distinguish between information resources and data resources. Data quality affects data value and the study of Ahituv (1989) identifies influencing factors for the value of information (Otto, 2015). The influencing factors for the value of information are classified into four categories (timeliness, contents, format, cost) (Ahituv, 1989). Except "Currency", "Completeness" and "Accuracy", all named data quality and data value attributes are already covered in the taxonomy. The currency of data can be distinguished in forecast, up-to-date and outdated. Completeness and accuracy are very situational attributes. Therefore, a distinction between low, medium and high is appropriate. For assessing the completeness, the conceptual representation of supply network structure data sources (figure 1) can be helpful.

Data Sharing: The shareability of data can be distinguished in proprietary, free and open. Free and open data are allowed to being shared. The difference is that the source of free data always has to be disclosed. However, it is not allowed to share proprietary data (Otto, Abraham and Schlosser, 2014).

5 Application

Prerequisite for the application of the taxonomy is the identification of data sources, which should be described or compared for linking processes. The conceptual representation (figure 1) is used for identifying potential data sources, by demonstrating the relevant data entities and attributes.

Through applying the taxonomy on the identified data source, the taxonomy is instantiated. Therefore, each dimension of the taxonomy is analyzed and the corresponding characteristics of the data source are identified. As a result of the application process, the identified characteristics are highlighted in the taxonomy or written in a new table like in section 6. An important factor for an effective application process are the involved roles. Very suitable roles from a knowledge and capability perspective are data stewards, data owners, data architects and data scientists (Otto, Abraham and Schlosser, 2014).

6 Demonstration

According to Hevner, March and Park (2004), case studies are a suitable demonstration method for artifacts. In order to demonstrate the applicability of the developed conceptual representation of supply network structure data sources and the taxonomy, the authors make case studies with two German OEMs. The data source availability is the superior and most selective data source dimension in the taxonomy. Therefore, each case study covers one data source scenario for each characteristic of that dimension (internal, external-closed, external-open).

The authors perform one workshop with each OEM. The workshops are divided into several steps. The first step is an introduction to the paper‘s topic and its goals. After that, the workshop participants discuss the dimensions and characteristics of the taxonomy. The results of that discussion are already considered in the taxonomy (figure 2). Step three is the collective decision of the data sources for the three data source scenarios. The selected data sources should have the potential for reconstructing the supply network structure of the OEM, which is determined by using the conceptual representation of supply network structure data sources (figure 1). Step four is the application of the taxonomy for each scenario. The last step is a brainstorming session in order to obtain feedback to the data model and the taxonomy. The participants and results of both workshops are described below.

6.1 Case 1 - OEM 1

The participants of the workshop are the manager of the department “Information Processes Logistics”, one data architect and one data scientist. The results of the discussion about the dimensions and characteristics of the taxonomy (step

Table 1: Scenario I - SAP MM from the OEM

Dimension	Characteristics
Data Source Availability	Internal
Data Source Interface	Internal Interconnection
Data Source Pricing Model	No
Data Aggregation	Database, Records, Items
Data Occurence/Update	Event-Driven Batch, Time-Driven Batch
Data Ownership	One Legal Entity
Data Structure	Structured, Semi-Structured
Data Format	Proprietary
Intra Data Standardization	Semantics, Syntax, Values
Inter Data Standardization	Semantics
Data Currency	Forecast, Up-To-Date, Outdated
Data Completeness	High
Data Accuracy	High
Data Sharing	Proprietary

two) are two changes in the taxonomy. The name of the dimension “Data Organization” changes to “Data Aggregation”. Data Organization does not describe the corresponding characteristics well. Organization is a very general term and leads to a lack of clarity. The OEM has future supplier relations in his ERP system. Thus, the characteristic “Forecast” becomes part of the dimension “Data Currency”.

In step three, the participants decide about the IT systems or rather data sources for the three scenarios, by using the conceptual representation. The first scenario is about the OEM’s internal SAP MM (Materials Management) system. The Material Management module is part of the SAP ERP (Enterprise Resource Planning). It contains material, supplier and other master data. Furthermore, it contains transaction data about material flows from the supplier to the OEM. The scenario about the internal SAP MM data source is summarized in table 1.

Scenario II is about the SAP MM system of a 1-tier supplier, which is an external and closed data source. In contrast to the OEM’s SAP MM system, there is master data and transactional data about 2-tier supplier, which are part of the supply network from the OEM. Table 2 includes the characteristics of the data source “SAP MM from a 1-tier supplier”.

Table 2: Scenario II - SAP MM from a 1-tier supplier

Dimension	Characteristics
Data Source Availability	External-Closed
Data Source Interface	Traditional EDI, Web Services, Offline Data Dump
Data Source Pricing Model	No
Data Aggregation	Records, Items
Data Occurence/Update	Event-Driven Batch, Time-Driven Batch
Data Ownership	One Lega Entity
Data Structure	Structured, Semi-Structured
Data Format	Proprietary
Intra Data Standardization	Semantics, Syntax, Values
Inter Data Standardization	Semantics
Data Currency	Forecast, Up-To-Date, Outdated
Data Completeness	High
Data Accuracy	High
Data Sharing	Proprietary

For scenario III the open data source “Eurostat” (2017) is used, which provides databases like statistics about international sourcing activities, subsidiaries and air freight transports (table 3).

In the feedback session, the participants report a good level of satisfaction with the workshop results. In their opinion, the results provide clear insights into the different characteristics of the available data sources. The conceptual representation and the taxonomy are a useful support to identify the data sources with a high potential for increasing the supply network structure visibility. The determination of the data source characteristics presupposes knowledge and experience in the field of data science. That is the critique of the participants because data scientists are rare in this company. In conclusion, the department “Information Processes Logistics” will use the taxonomy to compare data sources for future linking projects. They have a number of project requests from operational logistics departments, which need more data about the supply network for a proactive risk management.

Table 3: Scenario III - Eurostat

Dimension	Characteristics
Data Source Availability	External-Open
Data Source Interface	Web Services, Offline Data Dump
Data Source Pricing Model	No
Data Aggregation	Records
Data Occurence/Update	Event-Driven Batch, Time-Driven Batch
Data Ownership	Public
Data Structure	Structured
Data Format	Open
Intra Data Standardization	Semantics, Values
Inter Data Standardization	No
Data Currency	Outdated
Data Completeness	Low
Data Accuracy	Medium
Data Sharing	Open

6.2 Case 2 - OEM 2

The participants of the workshop are the head of the department “Information management of Procurement” and two data scientists.

In step two the participants discuss and review the taxonomy. The outcomes are two changes. The first one is adding the characteristic “No” to the dimension “Data Standardization”. This value is rarely needed in a business application focus, but it becomes important when external data sources are investigated. The second change is the partition of the dimension “Data Standardization” into “Intra Data Standardization” and “Inter Data Standardization”. The intra standardization refers to standardization inside a data source. The inter standardization describes the degree of standardization over various data sources.

In step three, the participants choose three scenarios to demonstrate the taxonomy. Scenario IV is about the OEM’s internal and customized visual basic application, which is based on a spreadsheet for the purpose of capacity management. It contains material, supplier and other master data. Furthermore, it contains transaction data about material flows between sub-supplier, supplier

Table 4: Scenario IV - Spreadsheet for Capacity Management

Dimension	Characteristics
Data Source Availability	Internal
Data Source Interface	Offline Data Dump
Data Source Pricing Model	No
Data Aggregation	Records
Data Occurence/Update	Event-Driven Batch
Data Ownership	One Legal Entity
Data Structure	Structured
Data Format	Proprietary
Intra Data Standardization	Semantics, Syntax, Values
Inter Data Standardization	No
Data Currency	Up-To-Date
Data Completeness	High
Data Accuracy	High
Data Sharing	Proprietary

and the OEM. Table 4 summarizes the characteristic of the Spreadsheet for Capacity Management.

The fifth scenario (table 5) is about an external data source. The market research firm "IHS" provides a collection of automotive supplier relationships called "Who Supplies Whom". It contains data about 700 supplier and their automotive components, modules and systems. The online accessible demo data source does not provide a full access (IHS, 2017). The whole data set is just available for registered customers. This is the reason why the data source is characterized as external and closed.

The sixth demonstration scenario is about an external and open data source. Online news and press releases are available on the internet and provide data about relations between companies. An example for supply network structure data in online news is the product press release on a supplier website (AGC, 2017). Table 6 summarizes the scenario about online news and press releases.

The brainstorming session in the last step of the workshop brings up the following feedback from the participants. The taxonomy clarifies the differences and similarities of public data sources and data sources, which are liable to costs.

Table 5: Scenario V - IHS Who Supplies Whom

Dimension	Characteristics
Data Source Availability	External-Closed (only demo is open)
Data Source Interface	Web Services, Offline Data Dump
Data Source Pricing Model	Volume-Driven, Time-Driven
Data Aggregation	Database
Data Occurence/Update	Time-Driven Batch
Data Ownership	One Legal Entity
Data Structure	Structured
Data Format	Proprietary
Intra Data Standardization	Semantics, Syntax, Values
Inter Data Standardization	Semantics
Data Currency	Up-To-Date, Forecast
Data Completeness	High
Data Accuracy	High
Data Sharing	Proprietary

Table 6: Scenario VI - Online news and press releases

Dimension	Characteristics
Data Source Availability	External-Open
Data Source Interface	Web Services
Data Source Pricing Model	No
Data Aggregation	Item
Data Occurence/Update	Event-Driven Batch
Data Ownership	One Legal Entity, Community, Public
Data Structure	Unstructured
Data Format	Open
Intra Data Standardization	No
Inter Data Standardization	No
Data Currency	Up-To-Date
Data Completeness	Medium
Data Accuracy	Medium
Data Sharing	Proprietary, Free, Open

Therefore, it is simpler to identify weak spots of a data source and make a decision based on objective criteria. The conceptual representation helps to focus on the essential data source content and supports the selection processes of the large number of available data sources. A way to quantify the suitability of data sources for increasing the supply network structure visibility, would be a field for future research. The quantification helps to identify the most suitable data source for a linking project with current data sources. The department "Information management of Procurement" expects a strategic advantage for sourcing and supplying processes by increasing the supply network structure visibility.

7 Conclusion

Following the design science research process, this research addresses two questions to implement a higher supply network structure visibility through the linking of different data sources. The first question, how a conceptual representation for automotive supply network structure data sources looks like, is answered with an entity relationship model. It defines the essential content, a data source about automotive supply network structure has to have. More particularly, the model clarifies the necessary entities and attributes of a data source for improving the supply network structure visibility. The second question deals with a taxonomy of data sources for supply network structures. The taxonomy describes data sources using fourteen dimensions and up to four potential characteristics. The demonstration of both research results uses a case study with two German OEMs. The case study proves the utility of the conceptual representation and of the taxonomy, as a support to identify and describe data sources about supply network structures in a systematic way.

The paper contributes to practice and research. Practitioners in charge of the data management can use the conceptual representation in a first step to identify data sources for an initial selection. In the second step, the taxonomy enables them to describe and compare the data sources, with the goal to identify the most suitable data sources for the linking process. Furthermore, they get a general understanding of the data sources, which is needed to negotiate about data source sharing and evaluate the data source portfolio. For example, potential data sources are owned by data providers or other supply chain members like supplier and logistics contractors. For researchers, the conceptual representation and the taxonomy add to the growing knowledge base of supply network visibility and are a basis for future research in the field of linking data sources.

Even with the promising results of the demonstration in a business environment, the authors cannot ensure that the taxonomy is complete. Both companies from the case studies are German automotive Original Equipment Manufacturers. Thus, more review and evaluation iterations in other industries are a valid field for future research.

References

Achilles (2017). *Helping automotive companies manage supply chain compliance and meet regulatory and legislative demands*.

AGC (2017). *Press release*. http://www.agc-glass.eu/English/Homepage/News/Press-room/Press-Detail-Page/page.aspx/979?pressitemid=3612.

Ahituv, N. (1989). "Assessing the value of information". In: *Proceedings of the tenth international conference on Information Systems - ICIS '89*. Ed. by J. I. DeGross, J. C. Henderson, and B. R. Konsynski. New York, New York, USA: ACM Press, pp. 315–325.

Awan, I., ed. (2015). *3rd International Conference on Future Internet of Things and Cloud: 24 - 26 Aug. 2015, Rome, Italy*. Piscataway, NJ: IEEE.

Basole, R. C. and M. A. Bellamy (2014). "Visual analysis of supply network risks: Insights from the electronics industry". In: *Decision Support Systems* 67, pp. 109–120.

Bergamaschi, S., D. Beneventano, F. Guerr, and M. Orsini (2011). "Data Integration". In: *Handbook of conceptual modeling*. Ed. by B. Thalheim and D. W. Embley. Berlin and New York: Springer, pp. 441–476.

Bowersox, D. J., T. Stank, and D. Closs (2000). "Ten Mega-Trends That Will Revolutionize Supply Chain Logistics". In: *Journal of Business Logistics* 21, pp. 1–16.

Bundesvereinigung Logistik e.V., ed. (2014). *7th International Scientific Symposium on Logistics: Germany, 4 - 5 Jun. 2014*.

Cagliano, R., F. Caniato, and G. Spina (2004). "Lean, Agile and traditional supply: How do they impact manufacturing performance?" In: *Journal of Purchasing and Supply Management* 10.4-5, pp. 151–164.

Chen, P. P.-S. (1976). "The entity-relationship model—toward a unified view of data". In: *ACM Transactions on Database Systems* 1.1, pp. 9–36.

Choi, T. Y. and Y. Hong (2002). "Unveiling the structure of supply networks: Case studies in Honda, Acura, and DaimlerChrysler". In: *Journal of Operations Management* 20.5, pp. 469–493.

Christopher, M. and H. Lee (2004). "Mitigating supply chain risk through improved confidence". In: *International Journal of Physical Distribution & Logistics Management* 34.5.

DeGross, J. I., J. C. Henderson, and B. R. Konsynski, eds. (1989). *Proceedings of the tenth international conference on Information Systems - ICIS '89*. New York, New York, USA: ACM Press.

eCl@ss (2017). *Classification and Product Description*. http://wiki.eclass.eu/w/index.php?title=File:ReleaseNotesBasicClassificationClass.JPG&filetimestamp=20120227160627.

Education Special Interest Group of AITP, ed. (2000). *Proceedings ISECON 2000*.

Eurostat (2017). *Your key to European statistics*. http://ec.europa.eu/eurostat/data/database.
Frohlich, M. T. and R. Westbrook (2001). “Arcs of integration: an international study of supply chain strategies”. In: *Journal of Operations Management* 19, pp. 185–200.
Grubic, T. and I.-S. Fan (2010). “Supply chain ontology: Review, analysis and synthesis”. In: *Computers in Industry* 61.8, pp. 776–786.
Harland, C. M. (1996). “Supply Chain Management, Purchasing and Supply Management, Logistics, Vertical Integration, Materials Management and Supply Chain Dynamics”. In: *Blackwell Encyclopedic dictionary of operations management* 15.
Hazen, B. T., C. A. Boone, J. D. Ezell, and L. A. Jones-Farmer (2014). “Data quality for data science, predictive analytics, and big data in supply chain management: An introduction to the problem and suggestions for research and applications”. In: *International Journal of Production Economics* 154, pp. 72–80.
Hevner, A. R., S. T. March, and J. Park (2004). “Design Science in Information Systems Research”. In: *MIS Quarterly* 28.75-105.
ICISCE, ed. (2015). *2nd International Conference on Information Science and Control Engineering (ICISCE), 2015: 24 - 26 April 2015, Shanghai, China*. Piscataway, NJ: IEEE.
IEEM, ed. (2014). *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM): 9 - 12 Dec. 2014, Malaysia*. Piscataway, NJ: IEEE.
IHS (2014). *Auto Tech Report: Infotainment Market Overview*. http://shop.ihs.com/buy/en/ihs/auto-tech-report-infotainment-market-overview-3000006155.
IHS (2017). *Who Supplies Whom*. http://www.ihssupplierinsight.com/shop/product/261/who-supplies-whom-complete-database.
Kubler, S., M.-J. Yoo, C. Cassagnes, K. Framling, D. Kiritsis, and M. Skilton (2015). “Opportunity to Leverage Information-as-an-Asset in the IoT”. In: *3rd International Conference on Future Internet of Things and Cloud*. Ed. by I. Awan. Piscataway, NJ: IEEE, pp. 64–71.
Kulp, S. C., H. L. Lee, and E. Ofek (2004). “Manufacturer Benefits from Information Integration with Retail Customers”. In: *Management Science* 50.4, pp. 431–444.
Levary, R. R. (2000). “Better supply chains through information technology”. In: *Industrial Management* 42.3.
Leveling, J., M. Edelbrock, and B. Otto (2014). “Big data analytics for supply chain management”. In: *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*. Ed. by IEEM. Piscataway, NJ: IEEE, pp. 918–922.
Li, B., L. Sun, and R. Tian (2015). “Multi-source Heterogeneous Data Exchange System for Cloud Services Platform Based on SaaS”. In: *2nd International Conference on Information Science and Control Engineering (ICISCE), 2015*. Ed. by ICISCE. Piscataway, NJ: IEEE, pp. 327–331.
Loh, T. C., S. C. L. Koh, and M. Simpson (2006). “An investigation of the value of becoming an extended enterprise”. In: *International Journal of Computer Integrated Manufacturing* 19.1, pp. 49–58.
Mukaddes, A. M. M., Choudhury, Abdul Anam Rashed, Abdul Malek, A. B. M., and J. Kaiser (2010). “Mukaddes 2010 - Developing and Information Model for Supply Chain Information Flow and its Management”. In: *International Journal of Innovation, Management and Technology* 1.2, pp. 226–231.
Murray-Rust, P., Neylon C., Pollock R., and J. Wilbanks (2010). *Panton Principles, Principles for open data in science*.

Nickerson, R. C., U. Varshney, and J. Muntermann (2013). “A method for taxonomy development and its application in information systems”. In: *European Journal of Information Systems* 22.3, pp. 336–359.

OSCM, ed. (2014). *6th International Conference on Operations and Supply Chain Management: 10-12 Dez. 2014, Bali*.

Otto, B. (2015). “Quality and Value of the Data Resource in Large Enterprises”. In: *Information Systems Management* 32.3, pp. 234–251.

Otto, B., R. Abraham, and S. Schlosser (2014). “Toward a Taxonomy of the Data Resource in the Networked Industry”. In: *7th International Scientific Symposium on Logistics*. Ed. by Bundesvereinigung Logistik e.V., pp. 382–421.

Panjivia (2017). *Powerful Insights with U.S. Customs Data*.

Patnayakuni, R., A. Rai, and N. Seth (2006). “Relational Antecedents of Information Flow Integration for Supply Chain Coordination”. In: *Journal of Management Information Systems* 23.1, pp. 13–49.

Peffers, K., T. Tuunanen, M. A. Rothenberger, and S. Chatterjee (2007). “A Design Science Research Methodology for Information Systems Research”. In: *Journal of Management Information Systems* 24.3, pp. 45–77.

Pidun, T. and C. Felden (2012). “Two Cases on How to Improve the Visibility of Business Process Performance”. In: *45th Hawaii International Conference on System Science*. Ed. by R. H. Sprague. Piscataway, NJ: IEEE, pp. 4396–4405.

Ramdas, K. and R. E. Spekman (2000). “Chain or Shackles: Understanding What Drives Supply-Chain Performance”. In: *Interfaces* 30.4, pp. 3–21.

Rosenzweig, E. D., A. V. Roth, and J. W. Dean (2003). “The influence of an integration strategy on competitive capabilities and business performance: An exploratory study of consumer products manufacturers”. In: *Journal of Operations Management* 21.4, pp. 437–456.

Rozados, I. V. and B. Tjahjono (2014). “Big Data Analytics in Supply Chain Management: Trends and Related Research”. In: *6th International Conference on Operations and Supply Chain Management*. Ed. by OSCM.

Sprague, R. H., ed. (2012). *45th Hawaii International Conference on System Science: (HICSS) ; USA, 4 - 7 Jan. 2012*. Piscataway, NJ: IEEE.

Tang, C. and B. Tomlin (2008). “The power of flexibility for mitigating supply chain risks”. In: *International Journal of Production Economics* 116.1, pp. 12–27.

Thalheim, B. and D. W. Embley, eds. (2011). *Handbook of conceptual modeling: Theory, practice, and research challenges*. Berlin and New York: Springer.

Wang, X., T. N. Wong, and Z.-P. Fan (2013). “Ontology-based supply chain decision support for steel manufacturers in China”. In: *Expert Systems with Applications* 40.18, pp. 7519–7533.

Ye, Y., D. Yang, Z. Jiang, and L. Tong (2008). “Ontology-based semantic models for supply chain management”. In: *The International Journal of Advanced Manufacturing Technology* 37.11-12, pp. 1250–1260.

Yu, Z., H. Yan, and T. C. Edwin Cheng (2001). “Benefits of information sharing with supply chain partnerships”. In: *Industrial Management & Data Systems* 101.3, pp. 114–121.

Zhao, X., J. Xie, and W. J. Zhang (2002). “The impact of information sharing and ordering co–ordination on supply chain performance”. In: *Supply Chain Management: An International Journal* 7.1, pp. 24–40.

Zilbert, A. B. (2000). “A Comparative Study of Traditional Electronic Data Interchange versus Internet Electronic Data Interchange”. In: *Proceedings ISECON 2000*. Ed. by Education Special Interest Group of AITP.

Transforming Blood Supply Chain Management with Internet of Things Paradigm

Wijai Boonyanusith[1], Phongchai Jittamai[1]

1 – Suranaree University of Technology

Internet of Things (IoT) paradigm has transformed the traditional healthcare system into the smart one. The IoT-based healthcare system is able to connect all available resources to operate healthcare services via the internet network. It would maximize the utilization of healthcare resources such as blood and blood products, which are scarce resources. Blood supply chain is a challenging system to manage, which researchers usually study for improved methodologies to boost its operation efficiency. Thus, this paper applied a content analysis in order to propose guidelines for enhancing and transforming the blood supply chain management based on the theoretical considerations in the IoT paradigm. The implementation strategies are provided to point out the issues that blood utilization and blood operational decision makings can be improved. Finally, the IoT-based framework of blood supply chain management is proposed to conceptualize the interactions between things, humans, processes, and service operations in the blood supply chain management.

Keywords: Blood Supply Chain; Internet of Things; Healthcare Services; Logistics Management

1 Introduction

Internet of Things (IoT) has been highlighted as a new intelligent tool for the ICT industry. IoT incorporates advance technologies that facilitate applications, devices, and objects to communicate among themselves through the connected networks (Tarouco et al., 2012). The IoT technologies mainly consist of information generation, collection and sharing as well as big data management and service application. Initially, the IoT has been used in the transportation tracking, information pricing of products, and map navigation. However, the advance technologies such as wireless, cloud based network, smart phones, wearable devices, and high speed connection have incorporated these IoT services into daily life activities. The IoT paradigm has applied multidiscipline knowledge and transformed the service platform to be more intelligent. It has become a useful tool in the market and its popularity has been on the rise after the introduction of many new concepts such as Smart City, Smart Home, and Smart Health (Kang et al., 2015). According to the health context, the IoT has been widely used in various healthcare services (Fernandez and Pallis, 2014). In the IoT-based healthcare, there are interactions between things (applications) and humans (practitioners and patients) in order to obtain real-time data and support decision-making activities for care deliveries and other associated services. Several works have been conducted with the use of IoT technologies to the healthcare domain including pervasive healthcare (Schreier, 2010; Doukas and Maglogiannis, 2010), and drug interaction checking (Jara et al., 20106). Many researchers have raised the issue of the IoT capabilities in healthcare systems in order to develop medical applications based on the IoT technologies (Bui and Zorzi, 2011). Moreover, the IoT would increase the utilization of resources in the healthcare environment, for example, managing limited resources for elderly care in the community more effectively (Feki et al., 2013; Li et al., 2011). The IoT-based healthcare system is able to connect to available resources in order to operate healthcare actions via the internet network. According to the benefits of the resource mobility, this IoT concept could also be applied to manage other resources in the healthcare domain such as specimen, vaccines, and blood products.

Blood is one of the most important resources in the healthcare system (Nagurney, Masoumi and Yu, 2012). Demand for blood usage caused by the illness of human is uncontrollable. Blood supply is also collected from human beings who have willingness to donate. Uncertainties in blood demand and supply are inevitable. Blood is perishable product, and its lifetime is within a short time period after collecting. The balance of blood demand and supply in the system has direct impact on the survival of the patient. This makes the task of managing the blood supply chain to be a challenging one (Dobbin, Wilding and Cotton, 2009). Due to an increasing blood demand, new methods for improving blood supply chain management are necessary (Rytila and Spens, 2006). Consequently, the motivation of this paper is to incorporate the IoT paradigm in managing the blood supply chain in order to propose guidelines for elevating blood demand and supply fulfillment services.

2 IoT Applications in Healthcare Domain

The IoT-based applications in the healthcare domain can be classified into four main groups which are tracking, identification and authentication, automatic data collection, and sensing (Vilamovska et al., 2009).

2.1 Tracking

Tracking is to identify the flow of people or objects while transferring. The function involves the real-time tracking such as patient-flow monitoring, workflows in hospital departments, and tracking of motions through bottleneck points. Tracking is mostly applied to real-time inventory location tracing in order to maintain the available resources and usage monitoring. Particularly, it is used for materials tracking during operations, such as specimen and blood products.

2.2 Identification and Authentication

Mainly, this step assures accurate patient identification with matching medical record, proper treatment and medication in order to prevent any damage to any patient. Authentication is fundamental security protocol for medical practitioners to access patients' information. Moreover, the function is used as security protection to prevent the losses of medical resources.

2.3 Automatic Data Collection

Automatic data collection is functioned to collect data form various operational processes in order to minimize processing time, enhance automated process, improve care and procedure traceability, and heighten inventory management. This function is integrated with the radio-frequency identification (RFID) technology to collect comprehensive real-time health information of the patient with the medical applications through the connected networks.

2.4 Sensing

Sensors can be applied both for in-patient and out-patient care operations. Its functions have ability to drive the patient into the center of processes such as diagnosing conditions, providing patient health information, monitoring patient behaviors, and alerting patient drug prescriptions. Wireless access-based network systems can be used to reach the patient everywhere, with the support of bio-signal monitoring of wearable devices.

In the healthcare domain, the IoT-based applications consist of these four aforementioned main functions. This paper has incorporated this paradigm to propose the guidelines to improve performances in blood service operations.

3 Blood Supply Chain Management

Managing the blood supply chain is one of the challenging operations research problems in the supply chain literature (Pierskalla, 2005). Practically, blood service operations involve blood collection, processing, inventory management, distribution, blood-banking management, and transfusion. Blood Center collects whole blood from donors, processes it into blood products at a Regional Blood Center and distributes them to hospitals in the network in order to transfuse to the patient. The main objective is to maximize blood utilization by minimizing both blood shortage and outdate rates in the system. The diagram of blood supply chain processes is shown in Figure 1.

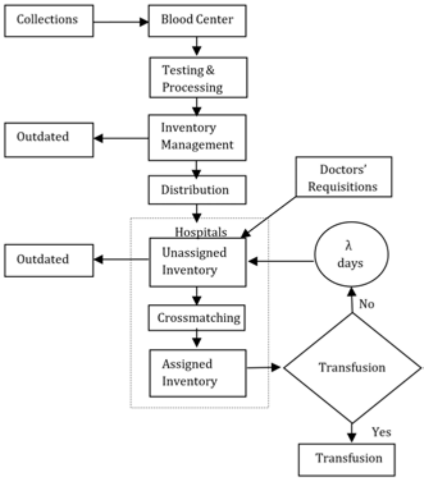

Figure 1: Blood supply chain diagram

3.1 Regional Blood Center

Regional Blood Center (RBC) has principal operations for blood collection, processing and testing, production, inventory management, and distribution to hospitals. Blood collection is to acquire the whole blood from donors, including donor recruitment and promotion. Collected whole blood units are tested in the laboratory for infectious agents and negative blood units. Then they will be processed into blood products and kept in the RBC storage facility. RBC is responsible for managing this inventory and allocating available blood units to hospitals according to requisitions from their local blood banks.

3.2 Hospital Blood Bank

Each hospital blood bank (HBB) has to manage blood inventory and its operations within the hospital. Doctors put requests for the certain amount and groups of blood products for patients' treatments. When available blood products are assigned for any patient, these units will be crossmatched to verify the compatibility with each particular patient. Crossmatched units will be stored in the assigned inventory and these units may not always be used because either doctors may postpone operations or there are blood units left after patients' treatments. These un-transfused units will be returned to the unassigned inventory if they do not expire. The period between blood crossmatching and releasing any unused units is called "a period for reserving blood". The longer this period is, the higher the probability that blood will expire before its actual use. Finally, the crossmatched units will be transfused to the patient for treatment.

4 Transforming Blood Supply Chain Management with IoT Paradigm

Blood supply chain is a challenging system to manage, which researchers usually study for improved methodologies to boost its operations. Most of the related works were involved with the use of operations research to study the associated problems in the context. There was also a literature review paper in the supply chain management of blood products (Beliën and Forcé, 2012) which presented a structured review in different perspectives for managing blood service operations. However, this paper investigated a few number of papers related to the technological issues and it did not provide trends in the technology aspect.

Moreover, there are some works related to the study of using RFID in the blood operations for tracking (Dvais et al., 2009), inventory management (Xu, Lian and Yao, 2013), and quality and safety (Briggs et al., 2009; Hohberger et al., 2012). These previous works pointed out the benefits of using this technology in managing blood. According to the arising trends in technologies, it would be beneficial to consider the possible advantages from using the IoT paradigm in the blood supply chain management. Thus, this paper applied a content analysis method to review the related works as well as investigating the blood service organizations in order to identify the opportunities for enhancing the blood supply chain performance based on the theoretical considerations in the IoT paradigm.

In practical, there is an implementation of RFID for blood management in each blood bag labeled in order to prevent medical errors in blood transfusion. It also provides blood tracking to the origin and to ensure the quality of blood products during the storage and transportation. However, the capabilities of IoT-based applications can be extended by the implementation of the RFID and the other functions to enhance the blood service operations more efficiently. This paper provides conceptual guidelines in transforming blood service operations management to enhance blood utilization with the IoT-based applications paradigm.

4.1 Tracking

4.1.1 Inventory count and location tracking

There are two main blood inventory storages in the supply chain, RBC and HBBs. RBC has to operate its inventory in order to fulfill demands from the HBBs in its network. In practical, there is a collaboration system between the RBC and the HBBs that helps managing blood supply throughout the network. However, in some developing and underdeveloped countries, there are not any efficient systems to track down the blood units from the donors to the patient. This issue could lead to the shortage of blood units in some hospitals where their HBBs' systems do not connect to the system of the RBC and the systems of other hospitals in the network. Real-time inventory count would be applied to check the collaborative inventory in order to automated count the overall blood stock levels in the HBBs. Hence, the RBC can obtain these counted blood stock data for future blood collection and replenishment planning. Moreover, the location tracking of each blood unit would enhance blood transshipment among the HBBs in case there are any blood emergency demand requests made from the HBBs and the RBC cannot supply enough blood units to responsd to those requests.

4.1.2 Safety and traceability

The blood traceability system is an online platform which is connected into the RFID-blood bag and barcode. It is able to integrate the sharing information and coordination among blood service organizations in the supply chain in order to mitigate blood transfusion risks to the patient, such as human error, incorrect blood products, and errors in medication administration (Dzik, 2007).

4.2 Identification and Authentication

4.2.1 Auto ID/bar code enabled transfusion administration

The identity check between each patient and particular blood product is the crucial task to avoid mistake in the transfusion. The RFID-blood bags and the traceability system can ensure that the right blood type with the correct quantity is always delivered to the right patient when there is a request (Koshio and Akiyama, 2009). The right information and the right process of transfusion are to be secured for the safety of the patient by using auto ID at the transfusion. RFID is used to guarantee that the right process is conducted according to the medical standard of transfusion. In case there are any complications after blood transfusion, this function is able to trace back information to the donor of that particular blood unit/product. Hence, RFID and barcode have capabilities of improving patient safety through managing transfusion activities and traceability of blood products to authenticate the right process and information.

4.3 Automatic Data Collection

4.3.1 Blood inventory management

Blood inventory is a crucial task in the supply chain. The main objective is to maximize blood utilization in such a way that blood shortage and outdated rates are at minimum levels. Using RFID and barcode to connect each blood bag to the blood inventory system can lead to the ability to manage blood information more efficiently. Real-time data of blood stock levels throughout the network would support blood collection planning for the RBC. The actual demand visibility can enhance an effective blood component production planning at the RBC in order to satisfy demands at each HBB. The blood operational costs are reduced because the RBC does not have to supply very large amount of blood units. Consequently, the blood outdated rate is minimized. Furthermore, using RFID and barcode to connect among the HBBs in the network can enhance the blood transshipment between the hospitals more rapidly when there are emergency demands in any specific groups needed and the RBC cannot response to these events.

4.3.2 Blood tracking and tracing

According to the use of RFID and barcode in the blood data connection, their functions completely support the blood tracking and tracing for expiration dates, blood shortage, and blood restocking requests at the HBBs. This smart network is capable of storing records of the dates and times of the blood expiration data so the RBC has the ability to track down the amount of blood units that are soon to expire. This information is beneficial for the RBC to set its blood rotation policy in order to minimize the number of expired blood units. Moreover, real-time blood tracking and tracing system will help the RBC to replenish its own inventory and allocate blood products to the hospital blood banks according to the specific demand from each hospital more efficiently.

4.3.3 Logistics management

Logistics activities in the blood supply chain management include blood collection, blood processing, inventory management, distribution, blood-banking management, and transfusion. The decision-making done in each process has direct impact on the subsequent processes. RFID and barcode can transmit relevant data within the blood operations management and they will provide real-time information for supporting various types of operational decisions in the blood service organizations. This function is also applicable to manage the stochastic data of blood demand and supply in order to reduce the uncertainties in the blood supply chain management.

4.4 Sensing

4.4.1 Transportation monitoring

Temperature control during transportation is vital for maintaining blood quality. Using sensing technology and real-time temperature tracking in blood transportation can ensure the quality of blood products. The sensing devices implemented for temperature tracking and measuring during the blood transportation could help ensuring the blood quality control during transportation in real-time. Moreover, the integration of the RFID system and the location tracking technology can provide information on the routes that tend to have oscillated temperature, which may be harmful to blood quality.

4.4.2 Patient monitoring

It is necessary for the medical practitioners to be alerted if the patient suffers any complication symptoms after receiving blood. A wearable bio-signal device that binds the patient to the system can be used to monitor and transmit data automatically back to the medical staff for any prompt treatments during postoperative blood transfusions.

In summary, blood service operations can be enhanced by using IoT-based applications. Tracking is used to operate the inventory counting and location tracking as well as to prevent the potential mistakes in blood transfusion. Identification and authentication function is integrated with the RFID technology in order to ensure the standard of the transfusion administration. Moreover, the IoT-based technologies allow the data collection to be conducted automatically, particularly the real-time blood inventory information at each storage location. Blood inventory tracking and tracing data in real-time could systematically enhance the collaboration processes between the RBC and the HBBs. Finally, sensing is aimed to improve the quality of the blood supply chain management by monitoring the temperature and locations of the blood products during transportation as well as monitoring post-transfusion reactions of the patient. The conceptual guidelines of transforming blood supply chain management with the IoT-based applications can be summarized in Table 1.

Table 1: Transforming blood supply chain management with IoT paradigm

IoT Applications	Blood Service Operations	Utilization
Tracking	Inventory count	Shortage minimization
	Location tracking	Transshipment utilization
	Safety and traceability	Safety and quality issues
Identification and authentication	Auto ID/bar code enabled transfusion administration	Safety of patients
Automatic data collection	Inventory management	Performance improving
	Blood tracking and tracing	Outdated minimization
	Logistics management	Performance improving
Sensing	Transportation monitoring	Quality of blood
	Patient monitoring	Safety of patients

5 Implementation Strategies

According to the aforementioned guidelines of transforming the blood supply chain management, this paper can briefly provide the implementation strategies in two issues, resource management and big data and knowledge management.

5.1 Resource Management to maximize blood utilization

Applying the IoT-based healthcare applications in the blood supply chain can enhance the performances in managing blood and blood products more systematically. The tracking function can maintain and control real-time blood stock levels in the hospitals, leading to the accurate blood collection planning. It allows the RBC to replenish the blood units and fulfill demands from the local blood banks more appropriately. This contributes to blood outdated rate reduction in the system. The connection of RFID and barcode can be used to manage the unused blood units in the hospitals by tracking down the remaining shelf-lives of blood units in the inventory. This could help reducing the number of blood shortage situations in the area. These proposed IoT-based applications could lead to more efficient blood rotation policy, where any unexpired blood units can be sent back to the RBC for further transshipping to the other hospitals. Moreover, it also yields the decreasing rate of blood expiration in the system.

5.2 Big Data and Knowledge Management to support decision makings in blood supply chain

Using automatic data collection and transferring enables the blood management system to store a large amount of useful data in the blood service organizations. In developed countries, a blood-banking system which links between blood centers and hospitals can be performed automatically to communicate or make decisions on blood service operations. However, in some countries where blood services still rely on personnel judgments, it is necessary to have information stored in the blood management system to use as a knowledge tool for supporting future decision-makings in any levels such as blood allocation policy, blood inventory management, and blood crossmatching policy. The extended network system is used to connect between blood service organizations and IoT-based blood service applications in order to enhance collaborative information sharing.

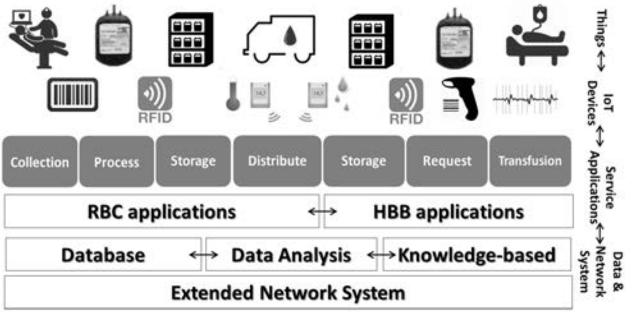

Figure 2: The IoT-based framework of the blood supply chain management

IoT-based technologies can be used to manage blood and blood products in order to minimize blood shortage and outdates rates. Blood service operations are systematically driven by the information together with the big data and knowledge management in order to support the operational decision makings in the blood supply chain management. The IoT-based framework of the blood supply chain management is presented in Figure 2.

6 Challenging Issues

The IoT-based blood supply chain management emphasizes the interactions between the blood service organizations. Blood service operations can be enhanced through the advantages of using these intelligent technologies which directly increase the blood utilization in the system. However, there are some challenging issues to take into consideration in order to transform the blood supply chain management with the IoT paradigm. These issues are briefly introduced as follows.

6.1 Barriers

Blood supply chain is a challenging system to manage. Its overall operations are complex which are associated with human, blood centers, hospitals, and patients. In theory, there are several studies that focused on the use of operations research in the blood operations problems. However, these works are too complex for application in the real context. Currently, there are advanced medical technologies that support various aspects of health services in order to improve the health outcomes of patients as well as enhance performances of care delivers, including Telemedicine, E-health, and IoT. Despite these benefits, Llewellyn et al. (2014) addressed barriers to the adoption and implementation of the advanced medical technologies. These barriers involve with the lack of encouragement from the Department of Health, change issues in new operational procedures, skills of practitioners, threats perception, leadership, infrastructure, project management, lack of knowledge toward new technologies, and costs. However, blood service operations depend largely on staff decisions which are also a main barrier in the adoption of the new advanced technologies in the healthcare context. In order to overcome these barriers, the empirical study on the advantages of the IoT application in the blood operations system is required to guarantee that such technologies are trustworthiness for investment in the real context.

6.2 Stakeholders' Complexities

Although the structures of the blood supply chain networks of different countries are not the same. But the main stakeholders commonly consist of regional blood center (RBC) and hospital blood banks (HBBs). Practically, the RBC is responsible for the blood collection, processing, production, and inventory management in order to allocate blood units to the HBBs. Each HBB has to manage its blood bank in order to provide blood units for the patients' treatments. The complexities among all stakeholders are involved with inter-organizational collaboration of the associated blood service operations from the human to the patient. The regulations and procedures in each stakeholder are different which make the IoT-based technologies difficult to implement in the entire system. System components, deployed technologies, and service applications should be well developed in order to connect among the stakeholders with the restrictions of privacy information in each organization.

Moreover, data sharing among the stakeholders is one of the most complexity issues in the blood supply chain system. In practical, the information systems among the stakeholders are not fully linked, because of the regulations and procedures in each organization. This problem causes the data transmission to be discontinuous among the networks. However, the HBBs have to provide actual demand data to the RBC so that the RBC in order to manage blood collection properly. The proposed IoT-based applications will allow the data transmission among the stakeholders to be real-time and more automatic. The visibility of blood information will reduce the uncertainty in blood service operations as well as improve blood management throughout the network.

The IoT-based applications can be applied to connect between the RBC and the HBBs for real-time data sharing in order to support the decision making in the blood service operations. Moreover, the IoT technologies can be used to manage blood inventory more systematically. The IoT-based system will automatically transmit the necessary information in order to mitigate the uncertainties in blood operations management as well. Thus, the consolidation of the blood service organizations is a key success towards the implementation of IoT-based applications in the blood supply chain management.

6.3 Architecture

The generic IoT-based system architecture consists of four layers which are sensing, network, service, and interface. There are brief details of its components to be addressed (Li, Xu and Zhao, 2015) as well as the issues in developing the architecture of the IoT-based applications in managing the blood supply chain. Sensing layer is able to track the environment and exchange information among devices by using tags or sensors. In the sensing layer, there are necessary issues to be concerned such as cost, size, resource, energy, deployment, heterogeneity, network communication, and protocol. Network layer is aimed to aggregate data from information technology infrastructures to transmit data in the environment. Also, there are primary issues to be addressed such as network management technologies, energy efficiency, quality of service, data and signal processing, and security. Moreover, all of the service activities are performed at the service layer such as information exchanging, data management, database, searching, and communication. There are main components to take into considerations, including service discovery and composition, trustworthiness management, and application programming interfaces. In interface layer, many devices are involved in the IoT-based applications. The compatibility issue of the various things should be addressed for the connected interactions in the environment.

6.4 Standardization

Standardizations are primary key to the success in the implementation of the IoT-based technologies in the system, including the blood supply chain. The standardizations must deliver interoperability, compatibility, reliability, and effectiveness of the operations in the environment. The RBC and the HBBs have to closely collaborate in determining policies and system architecture, ensuring the privacy, acceptability, security of networks, and developing joint standards in the IoT-based blood supply chain management system.

6.5 Security and Privacy

The architecture of the IoT system has an impact on the security and privacy of the stakeholders. The security requirements in the IoT system are addressed (Fabian and Gunther, 2007), including resilience to attacks, data authentication, access control, and information privacy. Moreover, information privacy is one of the most sensitive topics in the IoT area. Privacy Enhancing Technologies have been developed to provide information privacy such as Virtual Private Networks, Transport Layer Security, and Domain Name System Security Extensions. Stakeholders should contain these security and privacy requirements in their implementation plans for managing the blood supply chain with the IoT-based technologies.

7 Conclusions

IoT-based healthcare applications paradigm consists of four main functions, tracking, identification and authentication, automatic data collection, and sensing. This study has incorporated the IoT paradigm to provide the guidelines to transform the blood supply chain management in order to improve blood service operations. Tracking is used to monitor blood inventory counting and storage location. Identification and authentication is the function aimed to ensure that the blood transfusion standard is followed. Automatic data collection is used as a mechanism to drive the information flows in blood logistics operations. The use of sensing can improve the quality of blood during transportation as well as monitor the patient for irregularities during postoperative blood transfusion.

Furthermore, the implementation strategies are provided to point out the issues that blood utilization and blood operational decision makings can be improved. The IoT-based framework of the blood supply chain management is proposed to conceptualize the interactions between blood products, donors, patients, practitioners, processes, and service operation applications through the network connection. The challenging issues are discussed to provide further details in related aspects. The consolidation of the blood service organizations is a key success towards the implementation of IoT-based applications in the blood supply chain management in the real context.

References

Bui, N. and M. Zorzi (2011). "Health care applications: a solution based on the Internet of Things". In: *International symposium on applied sciences in biomedical and communication technologies*. Ed. by ACM. New York, p. 131.

Dobbin, J., R. Wilding, and S. Cotton (2009). "True blood: challenges of the blood supply chain in England". In: *Logistics & transport focus* 11.11, pp. 32–36.

Doukas, C. and I. Maglogiannis (2012). "Bringing IoT and cloud computing towards pervasive healthcare". In: *International conference on innovative mobile and internet services in ubiquitous computing (IMIS)*, pp. 922–926.

Dzik, W. H. (2007). "New technology for transfusion safety". In: *British journal of haematology* 136.2, pp. 181–190.

Feki, M. A., F. Kawsar, M. Boussard, and L. Trappeniers (2013). "The Internet of Things: the next technological revolution". In: *Computer* 46.2, pp. 24–25.

Fernandez, F. and G. C. Pallis (2014). "Opportunities and challenges of the Internet of Things for healthcare: systems engineering perspective". In: *International con-ference on wireless mobile communication and healthcare - transforming healthcare through innovations in mobile and wireless technologies (MOBI-HEALTH)*, pp. 263–266.

Jara, A. J., A. F. Alcolea, M. A. Zamora, A. F. G. Skarmeta, and M. Alsaedy (2010). "Drugs interaction checker based on IoT". In: *Internet of Things (IOT)*, pp. 1–8.

Kang, Y., M. Han, K. Han, and J. B. Kim (2015). "A study on the Internet of Things (IoT) applications". In: *International journal of software engineering and its applications* 9.9, pp. 117–126.

Koshio, A. and M. Akiyama (2009). "Blood transfusion and patient safety with IT - minimizing risk of transfusion with Point-of-Act-System". In: *International conference of the Asia-Pacific Medical Informatics Association*, pp. 46–53.

Li, X., R. X. Lu, X. H. Liang, X. M. Shen, J. M. Chen, and X. D. Lin (2011). "Smart community: an Internet of Things application". In: *IEEE Communication magazine* 49.11, pp. 68–75.

Nagurney, A., A. H. Masoumi, and M. Yu (2012). “Supply chain network operations management of a blood banking system with cost and risk minimization”. In: *Computational management science* 9, pp. 205–231.

Pierskalla, W. P. (2005). “Supply chain management of blood banks”. In: *Operations research and health care*, pp. 103–145.

Rytila., J. S. and K. M. Spens (2006). “Using simulation to increase efficiency in blood supply chains”. In: *Management research news* 29.12, pp. 801–819.

Schreier, G. (2010). *Pervasive healthcare via the Internet of Medical Things*. Graz, Austria: Austrian Institute of Technology GmbH.

Tarouco, L. M. R., L. M. Bertholdo, L. Z. Granville, L. M. R. Arbiza, F. Carbone, M. Marotta, and J. J. C. de Santanna (2012). “Internet of Things in healthcare: interoperability and security issues”. In: *conference on communications (ICC)*. Ed. by I. International. Ottawa, pp. 6121–6125.

Vilamovska, A. M., E. Hattziandreu, R. Schindler, C. Van Oranje, H. De Vries, and J. Krapelse (2009). *RFID application in healthcare - scoping and identifying areas for RFID deployment in healthcare delivery*. Tech. rep. RAND.

E-Cash & E-Vouchers: the Digitalization of the Humanitarian Aid and Logistics

Loïc Cohen[1], Vincent Salaun[1]

1 – CRET-Log Université Aix Marseille

In the recent years, the mobile phone coverage expansion and the more widespread use of cash cards have eased the implementation at scale of Cash and Vouchers (C&V) programmes in the humanitarian sector. Furthermore, the development of web-based interfaces, designed to respond to the specifics needs of the sector, supports the implementation of C&V programmes. Due to the technological innovations, C&V assistance is growing rapidly and the sector seriously considers the ''e-assistance" as an alternative to the in-kind assistance. This paper aims to investigate the potential impact of this digitalization on the humanitarian supply chain. If the literature states that C&V programming reduces cost, brings speed and serves better the needs of the beneficiaries, no real reference is made on the impact on the humanitarian supply chain. To explore this gap, the research uses the punctuated equilibria theory proposed by Eldredge and Gould (1972) and adapted for Management Sciences by several researchers such as Trushman and Romanelli (1985) or Rowe and Besson (2011). Having closes similarities with the humanitarian supply chain, a parallel is drawn with the event supply chain, which stands at a stage further in the integration of new technologies and has consequently re-shaped its structures and strategies. Through a qualitative methodology based on participant observations, institutional communications and secondary data, this paper highlights how C&V supported by digitalization has created a rupture in the role of the humanitarian logistics and how humanitarian organisations search to find a new equilibrium between strategy of intervention and supply chain strategy.

Keywords: Humanitarian logistics; Event logistics;Cash & Vouchers (C&V)

1 Introduction

Today, progress in new technologies raises a strong interest from donors, practitioners and governments as to how the technology can best serve humanitarian responses. In the recent years, Cash and Voucher (C&V) assistance is growing rapidly and many humanitarian agencies start to implement extensively this type of project as an alternative to in-kind assistance (Kovács, 2014). If there is currently no systematic tracking of the volume of humanitarian assistance delivered in the form of C&V, a report from ODI, (2016) suggests that in 2015, out of a total spending of 24 billion on humanitarian aid at least $1.9 billion was spent in the form of cash-based responses (51% cash and 49% vouchers). United Nations agencies accounted for around two-thirds of the total and non-governmental organisations (NGOs) for just under a third. At the World Humanitarian Summit in 2016, many of the world's largest humanitarian donors and agencies made a set of commitments to increase the use of cash-based programming (ODI, 2016).

If for a non-expert of humanitarian assistance, the C&V programming sounds like an anecdote, it is important to show how the digitalization of aid through C&V implies a change of paradigm for the humanitarian logistics. Since a long time, the traditional humanitarian aid is based on an ultime supply chain, as described by Mentzer et al. (2001), covering from the needs assessment to the distribution to the recipients. The C&V programming creates a significant break with this traditional model because it delegates all the downstream logistics operations to local traders. In this way, the C&V programming implies for the NGOs to move from a traditional in-kind assistance to a new financial and digitalized assistance, this is a move from physical flows management in the past, to information flows management in the future.

In this context of potential revolution for the NGOs, this research tries to understand what sort of impacts could have the C&V programmes by posing the following research question: How the C&V programmes can modify the logistics strategy of humanitarian NGOs?

This interrogation was raised by observations, from one of the authors involved in the sector as a logistician, of fast-paced changes in the humanitarian sector. Furthermore, this topic is often discussed in the different logistics coordination platforms by practitioners, as they feel that they have to redefine the logistics function because their role is challenged by a new type of assistance (Logistics cluster 2014).

To reply to this research question, this communication is divided in three sections. The first one highlights the principles of C&V programmes and humanitarian logistics, and draws a parallel with the event logistics using the punctuated equilibrium theory (Eldredge and Gould, 1972; Trushman et Romanelli, 1985), to show from a theoretical point of view how C&V programmes can change the NGOs logistics strategy. Subsequently, the second point focus on the qualitative methodology used for this research. The last point exposes a discussion of the results.

2 From humanitarian logistics to event logistics: a theoretical reading with the punctuated equilibrium

In order to establish a theoretical reading of the impact of C&V programmes on the logistics strategy of aid agencies, this part is segmented in four points: a review of the principles of C&V assistance (2.1), a literature review on the characteristics of humanitarian logistics (2.2), a parallel with another temporary logistics set-up, the event management and specifically on music festivals (2.3), to finish a reading by the punctuated equilibrium theory of the conclusions (2.4).

2.1 Cash & Vouchers programmes: the principles and operating

ECHO (2013), defined Cash-based responses as mechanisms to provide resources to a population in two main ways:

— Vouchers provide access to pre-defined commodities or services. They may be denominated in cash, commodities or service value. Vouchers come with some restrictions and must be exchanged for a given commodity or service. Vouchers are often grouped under the heading of 'cash-based responses', but they differ from cash transfers.

— Cash transfers are the provision of money to individuals, households, either as emergency relief intended to meet their basic needs for food, non-food items or services essential for the recovery of their livelihood. Beneficiaries decide how to use the cash received.

According to Doocy and Tappis (2016), in the different studies reviewed, C&V assistance appears to be more efficient to deliver when compared to in-kind assistances. However, the overall cost-efficiency of C&V depends on the prices paid by beneficiaries for the commodities in local markets compared to the cost for the humanitarian organisations to procure, transport, store and distribute the In-kind assistance (Venton et al, 2015).) The advantages of C&V have been segmented in three categories by WFP (2017). The first one, it's fast, efficient, and generally secure, by reducing the cost and logistical complexity, C&V shortens the path to deliver assistance. The second advantage is the C&V programme's ability to offer to beneficiaries a greater choice to purchase what they need most. And the last one concerns the potentiality to stimulate trade by injecting cash into the local economy, and to create a virtuous circle of production and consumption.

As stated by ECHO (2013), "In certain humanitarian disasters, the supply of food and non-food items to markets is organized and sustained. In such context, the cash and vouchers project gives the aid organisations the mean to reach timely and directly the affected population". However, despite the rapid growth and the clear advantages, C&V programmes are not suitable in all contexts. C&V assistance, or the combination with the In-kind assistance, should be defined by a context-specific assessment which analyses the availability of goods and services, the possible impacts on markets, the cost effectiveness, the technologies to support the transfer, the processes for targeting beneficiaries, the security and corruption risks.

Providing assistance to the peoples in need through cash and vouchers is not new; This mean of aid exists for over a century (Devereux 2006), but in the past, the C&V assistance implementation was hampered by the lack of technological solutions. In the recent years, the evolutions of the mobile telephony and electronic payment systems have allowed to switch from physical distributions to e-transfers and have facilitated the implementation of C&V programmes. There are two different forms of e-transfers used most frequently: The e-cash and the e-vouchers. A synthesis of differences and commons between e-cash and e-vouchers is suggested in the table 1.

As shown in this point, the e-cash and e-vouchers programmes are based on a transition from in-kind aid to a financial, direct or indirect, assistance allowed by the development of web-based interfaces and by adapting information technology to the crisis contexts. This kind of programme potentially implies for the NGOs to modify their deep organisation and more specifically their logistics strategy to move from a physical-based flow management to an information-based flow management. To continue our research, it seems important to return to the basics of humanitarian logistics to identify the potential impacts of e-transfers on the NGOs logistics strategies.

Table 1: Differences and commons between e-cash and e-voucher

	e-Cash	e-Voucher
Program Uses	Like cash, e-cash allows beneficiaries to buy which commodities are most, critical to them, and where and when they want to spend their money.	Like paper vouchers, evouchers are used in programmes designed to increase access to a particular set of goods or services.
Service Providers	Requires a local service provider (bank, mobile network, etc.) that can issue and accept e-cash.	Can be selected from a list of pre-qualified e-voucher service providers
Agent/Vendor Networks	Relies on a network of transfer agents or ATMs that accept e-cash in exchange for goods, services or physical cash.	Requires to establish a local vendors network. Also requires to equip vendors with hardware.
Availability and Regulations	Systems are local. Subject to banking and anti-money laundering regulations, some of which can require official forms of ID for programme participants.	Systems are global and can be used anywhere with minimum infrastructure requirements. Does not rely on, or link to, local financial services. Not subject to local banking or financial regulations.

Adapted from Mercy Corps e-Transfer Guide (2014)

2.2 Some basics about humanitarian logistics

When it comes to "humanitarian logistics", the most commonly used definition is: "Humanitarian logistics is the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from point of origin, to point of consumption for the purpose of meeting the end beneficiary's requirements" (Thomas and Mizushima, 2005).

To perform this task, the humanitarian logistics conducts needs assessments and logistics planning, manages the procurement cycles, organises the transports, performs customs clearance, manages warehousing and distributes the assistance to the beneficiaries.

As highlighted by Pettit and Beresford (2009), the supply chain management is often the most complex element of a humanitarian operation. The success or failure of such operations depends on understanding and addressing the issues of the supply chain. The difficulty of an emergency response is how to get the right quantities of relief supplies, to a determined location, in a minimum of time. This is the responsibility of the humanitarian logistics and to do so, humanitarian organisations have to put in place a complex and temporary network (Salaun, 2016) with multiples actors in charge of different nodes.

Many authors (Beamon 2004; Van Wassenhove, 2006; Kovacs and Spens, 2007; Day et al., 2012) have highlighted the Humanitarian Supply Chain Management characteristics and have identified five major components:

1. The unpredictability of the demand, which makes forecasting difficult, in terms of timing, location and volume.
2. The operational context, which makes very complex the effective flow of goods and materials.
3. The imperatives associated with the timeliness for a wide variety of supplies
4. The recurrent lack of resources in terms of supplies, expertise, technology, funding.
5. The supply chain is dynamic, temporary and short term.

The humanitarian sector regroups a wide panel of different types of organisations which range from NGOs, United Nations agencies, International organisations, etc. Although, if they operate in the same contexts, the place of the logistics within the organisation and the level of logistical capabilities vary from one organisation to another (Thomas & Kopczak, 2005). Some organisations consider the logistics as a central function, while some other organisations often neglect its role in the strategic planning (Kovacs & Spens, 2009). Various factors, such as their size, mandate, structure, funding and area of expertise determine their deep organisational structure and operational boundaries, which impact on their logistics strategy (Cohen, 2016).

Humanitarian logistics is caught in a vicious circle (see figure 1) where a lack of understanding and recognition of the importance of the function precludes it from planning and funding processes, leading logistics not to be able to fulfill its objectives and obligations.

In a sector where the logistics has been suffering for long from a lack of investment and has shown some chronical deficiencies, humanitarian logistics researchers are concerned with the implications and the complexity of the physical flows management. This includes the number of points at which the products are handled, moved and stored, regardless of the number of actors, transfers of responsibility and liability in the logistics process.

Moreover, Humanitarian organisations compete to access funding, and donors are demanding greater accountability and performance of the logistics activities. Since logistics accounts for about 60% of a relief operation (Van Wassenhove, 2006), improving its performance would surely give a ‘’competitive advantage” to organisations to access funding. As the basic principles of managing the flows of goods, information and finances, which are valid for the commercial logistics, are also valid for the humanitarian logistics (Kovacs and Spens, 2007), one envisaged way by certain organisations to improve the performance of their supply chain, is to delegate the management to Logistics Services Providers (Balcik et al., 2010). But from a contract management standpoint and given the unpredictable nature

Figure 1: The vicious circle of the humanitarian logistics from Van Wassenhove(2006)

of relief operations, it could be complex to delegate the management of the supply chain to logistics services providers (Cohen, 2016).

A closer look to this problematic reveals that the solution of improving the effectiveness of these supply chains may not be in the hands of these logistics operators, but maybe in the shift on how the assistance is delivered. Indeed, the e-assistance dematerialized and transformed the in kind-assistance from physical, informational and financial flows to informational and financial flows only. The complex physical flow management and the final distribution are delegated to local traders, who become de facto a new type of services providers. By the eliminating or transferring many logistical activities to third parties, C&V assistance modifies the humanitarian supply chain. It simplifies the complex procurement cycles, although there is still contracts management to do. But most of all, it is an opportunity to disengage from the transport and warehousing management and to reduce distribution implications. This shift on aid delivery mechanisms potentially leads to a reconfiguration of the logistics function (Heaslip 2013). However, this thinking stays an assumption and the lack of research about the impacts of C&V programmes on NGOs logistics strategy requires an extension of this research to strengthen our theoretical conclusions. For this, it’s possible to establish a parallel between the humanitarian logistics and another specific logistics, which is also engaged in the digitalization: the music festivals logistics.

2.3 Toward another digitalized logistics: the event management

The e-cash and e-vouchers programmes are new for practitioners and researchers, so it is difficult to identify the potential impacts of C&V programmes on the humanitarian logistics. However, it is possible to use the example of a near industry, which currently lives the same case of digitalization than the humanitarian aid. For few years, the event management sector is characterized for using more and more information technology. To illustrate this fact, we can look specifically on the music festivals industry which uses the cashless technology since the early 2010’s (Jackson, 2014).

At first glance, humanitarian and event logistics can be seen as very different industries: different aims, different stakeholders, different ”customers”, etc. However, as shown by Salaun (2016), if the stakeholders and the aims of these two industries are distinct, their deep structures are very similar: a permanent structure with a large network and a wide variety of actors to implement temporary projects (relief for humanitarian and festival for event). In fact, if we look at the major components of the humanitarian logistics highlighted previously, we can identify a lot in common with the event logistics. As shown by Lexhagen et al. (2005) and Locatelli and Mancini (2014), in event management, the ‘’operation excellence” is one of the biggest factors of success for any events. Even if these authors don’t give any exact definition of ”operation excellence”, it looks possible to associate this notion to the logistics performance. Like in the humanitarian context where the logistics is seen as essential, the logistics is crucial in event management. Moreover, according to Kerzner (2013), the two major reasons of an event failure are, the incapacity to respect the time restriction of the event, and the difficulties to address consumers’ demands due to a lack of resources or goods. Also, we can find two additional similarities between event and humanitarian industry: the short term cycle of the supply chain and the lack of resources. In addition, O’Toole (2000) reports one other characteristic for event logistics : the operation management complexity due to a wide variety of supplies, which is another similitude with the humanitarian logistics. According to these authors, event and humanitarian logistics are very close and are based on the same principles. This proximity between the two logistics permits to build these basic inferences:

- Humanitarian and event logistics are very similar.
- Event logistics has been impacted and continues to be impacted by an innovation, the cashless.
- Given the similarities with the event logistics, humanitarian logistics can also be impacted by innovations.

Before developing this idea, it is important to explain what is the cashless and how this innovation has strongly impacted the event logistics in music festivals. Used for a decade (Jackson, 2014), the cashless constitutes a personal and virtual wallet assigned to each festival-goers. This virtual wallet is linked to the bank account of the festival-goers who can put at any moment credits on it and which is materialized by a RFID or NFC tag included on a card or a bracelet. When a festival-goer wants to buy something, he presents his RFID tag to a terminal to pay (Dowson and Bassett, 2015). To our knowledge, the impacts of cashless on event logistics have been addressed only on two studies. The first one by Jackson (2014) shows how the cashless produces new information flows. The second one, leaded by Salaun (2017) highlights the capacity of the cashless to impact festivals logistics strategy on three points: the logistics processes (1), the warehousing (2), and the flows management (3). According to Jackson (2014) and Salaun (2017), in music festivals management, the cashless has impacted strongly the logistics strategy of the event and encouraged new logistics practices, such as subcontracting logistics services providers (Salaun, 2017). To explore the potential impacts of C&V programmes on NGOs logistics strategy, it could be pertinent to use the example of the cashless on event logistics: From a small digitalization to a big logistics revolution.

2.4 A reading of digitalization through the punctuated equilibrium theory

As shown in the previous point, the humanitarian and event logistics, at least in music festivals, present similarities. Therefore, it is possible to imagine that the impacts of the cashless on event logistics can potentially be transposed as the future impacts of C&V programmes on humanitarian logistics. In both situations, the opportunities permitted by the information technology evolution, lead to rethink the deep structure of organisations and to develop a new logistics focus on information flow management instead of physical flow management. In order to propose a framework to study the case of humanitarian logistics and C&V programmes, we need to embed our research in a stable theoretical frame in order to develop cross-sectorial extrapolations from event to humanitarian management.

The rapid development of cashless and C&V programmes which appears to be the consequences of fast evolutions of information technology used gradually by the actors of these two industries, suggests to use an evolutionist point of view, and more specifically the punctuated equilibrium theory. Historically, developed in the biology field by Eldredge and Gould (1972), the punctuated equilibrium theory proposes a gradual evolution and rejects the idea of a permanent adaptation to the environment. The evolution of organisms is based on the research of homeostatic equilibrium during long periods, punctuated by short and sudden periods of radical modifications linked to important changes of the environment. Adapted to management by Trushman and O'Reilly (1996), the punctuated equilibrium theory highlights how organisations quest for stability and homeostatic equilibrium, punctuated by swift periods of rupture and the re-reshape of the structure. This theory looks relevant to study the potential impacts of C&V programmes on humanitarian logistics strategies.

Even if this theory was developed in biology, the academic community of researchers on management uses frequently the punctuated equilibrium. For example, we can point out the works of Day (2014) and Stevens and Johnson (2016) who referred to the punctuated equilibrium on humanitarian logistics researches. One of the most important contribution of this theory is to show how the evolution cycles based on fast periods of rupture can modify the organisation deep structure (Gersick, 1991). According to Silva and Hirschheim (2007), the organisation deep structure can be splitted in four major components: the organisational culture (1), the distribution of power (2), the organisation (3), and the control and management system of performance (4). By comparing different models from the literature, including the model of Trushman and O'Reilly (1996), Besson and Rowe (2011, 2012) describe the evolution cycle in four steps:

1. Unfreeze, which is a rupture of the homeostatic equilibrium and a decrease of the organisation inertia.
2. Move, is a step of exploration and the emergence of a new deep structure.
3. Refreeze, corresponding to the stabilisation and the anchoring of the new deep structure.
4. Convergence, is the last step during which the organisation searches the optimisation and the routinisation of the new equilibrium.

According to the model of Besson and Rowe (2011, 2012), and with the information given by the literature about cashless in music festivals, it is possible to consider that music festivals are currently in the third step of the cycle of evolution, the refreeze. Indeed, in music festivals the organisational culture is modified to adopt the cashless technology. Some activities are subcontracted, as a power delegation. The organisations have been reconfigured to include the new information flow, and new ways of control and performance management have been developed and implemented. As per Silva and Hirschheim (2007), this description shows a modification of the deep structure of the music festivals organisations in order to find a fit with the new environment and opportunities. Concerning the impact of C&V programmes on humanitarian logistics, at this stage there is not enough information provided by the literature. Therefore, It would require a new empirical exploratory study to identify in which step of the cycle the humanitarian logistics is positioned, and then to use the analogy with the cashless to think ahead the evolution of the humanitarian logistics in the coming years.

3 Methodology of empirical study

In order to position the humanitarian logistics on the evolution cycle shown by Besson and Rowe (2011, 2012 and to try to foresee the impacts of C&V programmes on humanitarian logistics, this research is based on a qualitative methodology. This includes participant observations with the direct involvement of one of the researchers as practitioner in the humanitarian sector, who has analysed the impact of C&V programming on the logistics through the lens of the researcher /actor. As a member of a NGO involved in C&V programmes, the author has conducted discussions on this topic with different stakeholders in November 2016 in Nigeria, to understand how the actors perceive the impact of C&V on the logistics. Also, to support the analyse of empirical data, the results of a survey conducted in April 2014 by the Global Logistics Cluster (Logistics Cluster, 2014) to senior logisticians from different organisations (87 respondents from 24 organisations) have been used to capture more widely the perception from practitioners. In addition, to increase the validity of this research, two other ways of data collection were used: a collection of secondary data from academic and professional researches, and the exploitation of institutional and commercial communications from major C&V actors. In line with the exploratory nature of this research, the data were triangulated and exploited with the preconisation of Miles and Huberman (1984), in particular with the different matrix of their methodology. According to the target of the authors to highlight new hypothesis for future works, this research doesn't pretend to show an objective reality but just the perception from practitioners.

4 Findings and discussion

To expose the results, this last part is segmented in three points representing the evolution of the findings. A first point positions the humanitarian logistics in between the first and the second step of the cycle shown by Besson and Rowe (2011, 2012) (4.1), a second point develops an analogy with the impact of cashless in event logistics (4.2), a last point proposes a prospective view of possible impacts of C&V programmes on the humanitarian logistics (4.3).

4.1 The humanitarian logistics in between the first and the second step of the evolution

For diverse reasons, the humanitarian logistics suffers from chronical deficiencies and this represents a challenge for the sector. In addition, the rapid technology evolution offers the opportunity to digitalize the relief assistance and to deliver it by another mean, which has multiple advantages over the traditional in-kind assistance. The combination of these two factors pushes the organisations to break a long lasting equilibrium that they have built for decades, with the In-kind assistance model. Since, the sector has integrated this break and organisations realise the opportunities offered by the technology. Numerous aid agencies are developing new internal systems, capacities and ways of working for C&V programmes implementation (CaLP 2014).

This rupture engaged by humanitarian organisations corresponds to the stage One of the evolution cycle, the Unfreeze period.

In this move, the logistics sector tries to follow the pace and to clarify its role toward C&V programmes. The survey from the Global Logistics Cluster (Logistics Cluster, 2014), shows that humanitarian logisticians realise that their role will be transformed or diminished, and they expressed concerns about how their skills will be used in the e-assistance supply chain.

All these changes and the search from the actors to take position in the emergence of a new deep structure, clearly mark the entrance of the sector into the second stage which is the Move period defined by Besson and Rowe (2011, 2012). What we need to discuss now, is how this exploration/evolution phase will transform the humanitarian supply chain, which despite its deficiencies remains a key function in traditional in-kind assistance.

4.2 Using the experience of the event logistics to imagine the future of the humanitarian logistics

If the humanitarian logistics is currently in between the first and the second step of the evolution cycle from Besson and Rowe (2011, 2012), studies from Jackson, (2014) and Salaun, (2017) show how the event logistics can be positioned on the third step of cycle, which marks the evolution of the deep structure and the institutionalisation of new logistics practices. To illustrate the modification of the deep structure in event logistics due to the cashless technology, we can analyse information about one of the major music festivals in France (herein called Alpha Festival to conserve its anonymity). After only two editions with the cashless technology, the Alpha Festival has changed a large part of its logistics structure, including new access systems for the festival-goers, new management of food and beverage supplies, reduction of the waiting time to buy something during the event for the festival-goers, etc. All of this comes from the cashless technology and the possibilities offered by the new information flow. This new approach leads the organisation to modify at least three components of the deep structure: the organisation (new repartition of resources and competencies between the services), the management system of performance (new data for real-time management), and the delegation of power inside the organisation (new cashless technology suppliers and new information flow management specialists). A study of these two last points highlights the emergence of new actors inside the network. A new actor started with a ”simple” solution of cashless few years ago, but nowadays this same firm offers the possibility for the events to deploy cashless solutions with the back office software for the information flow management. As a logistics services provider who built and manage a full supply chain for a customer, the cashless provider offers a full package of solutions for event supply chain management. Based on this example of the cashless impact on event logistics, we can imagine a similar trajectory for the humanitarian logistics with the apparition of new actors in the future step of the evolution.

4.3 What humanitarian logistics in few years?

By creating a concept of e-assistance, C&V programmes can be considered as a major break in the humanitarian sector. To reach beneficiaries, C&V responses will increasingly rely on financial services providers, technology infrastructures and private sector capacities, where these exist. The growing demand for these services will in turn lead to an increasing number and diversity of enterprises seeking to engage with humanitarian agencies. As such, the traditional humanitarian actors will progressively forge new working relationships and the private sector will likely create further demand for its expertise by developing products and services designed to humanitarian C&V responses.

Thus, the aid agencies will have to rethink their strategy and to re-shape their organisational structure. This will strongly impact the supply chain and will lead to a redefinition of the logistics function. By this move to digitalization, organisations are transferring many logistical activities to third parties and they rely on the local market to transform the e-assistance into in-kind assistance. The technology interface virtually pilots the supply chain and the physical flows are handled by local traders who become de facto a new type of logistics services providers.

As well as in the music festivals sector, the humanitarian organisations will modify three main components of the deep structure. The organisational structure with a new repartition of resources and competencies within the organisation (less logistics, more C&V specialists), the performance evaluation (data available for a real-time monitoring), and the delegation of power to new actors (C&V technology suppliers and information management specialists). Consequently, as stated in the Global Logistics Cluster survey (Logistics Cluster, 2014), the logisticians perceive their role narrowed to market assessments, evaluation of local traders' supply chains capacity and contracts management with these new actors. But if the logisticians realise that their traditional role is challenged, they can also see an opportunity to perform better on the in –kind assistance delivery, considering that a part of the logistics burden has been removed due to C&V programmes. Consequently, more logistics capacity could be allocated to the in-kind assistance (Logistics Cluster, 2014).

Nonetheless, if the e-assistance will represent a consequent share of the humanitarian activities, C&V depends on the markets and the technology, it can't be generalised. The traditional logistics supporting the in-kind assistance will always be required where markets and technology infrastructures are dysfunctioning. In this perspective, we can imagine that the organisations deep structure would take an ambidextrous form, with the objective to maintain an equilibrium between exploitation and exploration in the different facets of the humanitarian assistance.

5 Conclusion

This research aims to highlight the potential impacts of C&V programmes on humanitarian logistics. By an analogy with the event logistics and with a reading through the punctuated equilibrium theory, this communication shows how the C&V programmes would potentially impact strongly the deep structure of NGOs and more specifically their logistics strategy.

Due to its exploratory nature, this research has important limitations. The first one is linked to the choice of methodology based on participant observation and exploitation of secondary data. To increase the validity of our conclusions, it seems important to develop a new empirical study with multiple cases analysis and maybe a longitudinal study to observe the real-time evolution of the logistics strategy of organisations involved in C&V programming. Despite these limits, this research is, to our knowledge, one of the first on this emerging topic of humanitarian supply chain digitalization. It opens a door for future researches on information flow management in crisis context with the e-assistance, the deep structure of supply chains and the evolution of the humanitarian sector.

Currently C&V programmes can be seen as a shift from the traditional In-kind assistance toward the e-assistance. In other words, it is a move from a logistics of physical flow to a logistics of information flow. This may imply three main modifications in the humanitarian supply chain. First, a focus on new core competencies in information flow management with a delegation to new actors such as C&V technology providers to pilot virtually the supply chain. Secondly, the reconfiguration of the traditional logistics roles with the delegation of the downstream supply chain management to local traders. Thirdly, the emergence of an ambidextrous supply chain with a redefinition of the logistics function in order to manage both in-kind and e-assistance.

But in this evolution it is important to keep in mind that the rush on C&V programmes and a possible push from donors to deal directly with the private sector, such as financial institutions and telecom companies, could backfire on aid agencies. They might lose footprint and influence on the ground and their role could be seriously challenged by new actors.

References

Balcik, B., B. M. Beamon, C. Krejci, K. Muramatsu, and M. Ramire (2010). “Coordination in humanitarian relief chains: Practices, challenges and opportunities”. In: *International Journal of Production Economics* 126.1, pp. 22–34.

Beamon, B. M. (2004). “Humanitarian relief chains: Issues and challenges”. In: San-Francisco.

Besson, P. and F. Rowe (2011). “Perspectives Sur le Phénomène de la Transformation Organisationnelle”. In: *Systèmes d’Information et Management* 16.1, pp. 3–34.

Besson, P. and F. Rowe (2012). “Strategizing Information Systems-enabled Organizational Transformation: A Transdisciplinary Review and New Directions”. In: *Journal of Strategic Information Systems* 21.2, pp. 103–124.

Cluster, L. (2014). *Logistics in Cash & Markets Survey*. Tech. rep.
Cohen, L. (2016). “The outsourcing decision process in humanitarian supply chain management evaluated through the TCE and RBV principles”. In: Lausanne.
Corps, M. (2014). *Cash Transfer Programming : E-transfer Implementation Guide*. Tech. rep.
Day, J. M. (2014). “Fostering emergent resilience: the complex adaptive supply network of disaster relief”. In: *International Journal of Production Research* 52.7, pp. 1970–1988.
Day, J. M., S. Melnyk, P. Larson, E. Davis, and D. Whybark (2012). “Humanitarian and disaster relief supply chains: a matter of life and death”. In: *Journal of Supply Chain Management* 48.2, pp. 21–36.
Devereux, S. (2006). “Cash transfers and social protection.” In: Johannesburg, pp. 9–10.
Doocy, S. and H. Tappis (2016). *Cash-based approaches in humanitarian emergencies : a systematic review*. Tech. rep. London: International Initiative for Impact Evaluation.
Eldredge, N. and S. Gould (1972). “unctuated Equilibria: An Alternative to Phyletic Gradualism”. In: *Models in Paleobiology*. San-Francisco: Freeman Cooper, pp. 82–115.
Gersick, C. J. G. (1991). “Revolutionary Change Theories: A Multilevel Exploration of the Punctuated Equilibrium Paradigm”. In: *The Academy of Management Review* 16.1, pp. 10–36.
Heaslip, G. (2013). “Services operations management and humanitarian logistics”. In: *Journal of Humanitarian Logistics and Supply Chain Management* 3.1, pp. 37–51.
Humanitarian Aid & Civil Protection (ECHO), E. C. D.-G. for (2013). *The Use of Cash and Vouchers in Humanitarian Crises. DG ECHO Funding Guidelines*. Tech. rep.
Jackson, C. (2014). “The lived esperience o the popular music festival-goer”. PhD in management. Bournemouth, UK: Bournemouth University.
Kerzner, H. R. (2013). *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*. en. 11e édition. Hoboken, N.J: John Wiley & Sons.
Kovacs, G. (2014). “Where next? The future of humanitarian logistics”. In: *Humanitarian Logistics: Meeting the Challenge of Peparing for and Responding to Disasters*. 2 ed. London: Kogan Page, pp. 275–286.
Kovacs, G. and K. Spens (2007). “Identifying challenges in humanitarian logistics”. In: *International Journal of Physical Distribution & Logistics Management* 37.2, pp. 99–114.
Kovács, G. and K. M. Spens (2007). “Humanitarian logistics in disaster relief operations”. In: *International Journal of Physical Distribution & Logistics Management* 37.2, pp. 99–114.
Lexhagen, M., H. Nysveen, and L. E. Hem (2005). “Festival coordination: an exploratory study on intention to use mobile devices for coordination of a festival”. In: *Event Management* 9.3, pp. 133–146.
Locatelli, G. and M. Mancini (2014). “Controlling the Delivering of Projects in Mega-Events: An Application on Expo 2015”. In: *Event Management* 18.3, pp. 285–301.
Mentzer, J. T., W. DeWitt, J. S. Keebler, S. Min, N. W. Nix, C. D. Smith, and Z. G. Zacharia (2001). “Defining Supply Chain Management”. en. In: *Journal of Business Logistics* 22.2, pp. 1–25.
Miles, M. B. and A. M. Huberman (1984). *Qualitative data analysis: a sourcebook of new methods*. en. Sage Publications.
O’Toole, W. (2000). “Towards the integration of event management best practice by the project management process”. In: *Event Beyond 2000*. Sydney.
Overseas Development Institute (2016). *Counting cash: tracking humanitarian expenditure on cash-based programming*. Tech. rep.

Pettit, S. and A. Beresford (2009). "Critical success factors in the context of humanitarian aid supply chains". In: *International Journal of Physical Distribution & Logistics Management* 39.6, pp. 450–468.

Pichault, F. and J. Nizet (2000). *Les pratiques de gestion des ressources humaines*. Paris: Seuil.

Salaun, V. (2016). "La pérennité des Organisations Temporaires (OT) : compréhension du rôle conjoint de la pulsation organisationnelle et de la logistique - L'apport de l'étude des festivals musicaux -". PhD in Management. Aix-en-Provence: Aix-Marseille Université.

Salaun, V. (2017). "Which evolutions of event logistics? The impact of cashless in music festivals". In: *Logistique & Management* 24.3-4, pp. 207–214.

Silva, L. and R. Hirschheim (2007). "Fighting against Windmills: Strategic Information Systems and Organizational Deep Structures". In: *MIS Quarterly* 31.2, pp. 327–354.

Stevens, G. C. and M. Johnson (2016). "Integrating the Supply Chain … 25 years on". In: *International Journal of Physical Distribution & Logistics Management* 46.1, pp. 19–42.

The Cash Learning Partnership CALP (2016). *Is Cash transfer programming fit for the future?* Tech. rep.

Thomas, A. and L. Kopczak (2005). *From Logistics to Supply Chain Management: The Path Forward in the Humanitarian Sector*. Tech. rep. San-Francisco: Fritz Institute.

Thomas, A. and M. Mizushima (2005). "Logistics training: neccessity or luxury?" In: *Forced MIgration Review* 22, pp. 60–21.

Trushman, M. and C. O'Reilly (1996). "Ambidextrous organizations : managing evolutionnary and revolutionnary change". In: *California Management Review* 38.4, pp. 8–30.

Van Wassenhove, L. (2006). "Blackett Memorial Lecture Humanitarian aid logistics: supply chain management in high gear". In: *Journal of Operational Research Society* 57, pp. 475–489.

Venton, C., S. Bailey, and S. Pongracz (2015). *Value for money in cash transfers in emergencies. Final Report*. Tech. rep. UK Department for International Development.

World Food Program (WFP) (n.d.). *Cash based transfers*. Tech. rep. http://www1.wfp.org/cash-based-transfers.

Business Model Innovation: A Case of the Offshore Lifting Equipment Supplier

Mikhail Shlopak[1], Richard Myhre[2], Gabriele Hofinger Jünge[3]

1 – Møreforsking Molde AS

2 – AXTech AS

3 – NTNU

The purpose of this paper is to present the background for and the process of development of an Internet of Things (IoT) business model (BM) for a Norwegian offshore lifting equipment supplier. The paper presents both challenges and new opportunities connected to the case company's transition towards IoT, service-based BM. The research methodology is a single case study research. The research approach involves four steps: theoretical discussion; a case study; analysis of the case study, and conclusions. The results show that development of an IoT BM by the case company led to new possibilities for monetization of data and offering new services. The authors suggest that manufacturing companies considering transition towards IoT BM focus on the overall IoT business case rather than on Local IoT solution return on investment (ROI). Studies analyzing the development process and results of implementation of IoT BMs by manufacturing companies are scarce. This paper aims to partially fill this gap by analyzing the experience of a real-world company that has developed and implemented the IoT BM. The research is limited to a single case company. Although the case company has developed and implemented its IoT BM, it is still in the transition process. For now, the company has not yet managed to get its new product rented out, which also creates limitations for drawing conclusions. This research contributes to the understanding of IoT BMs and assists managers who are responsible for developing and implementing IoT BMs.

Keywords: Internet of Things; Business models; Servitization; Engineer-to-Order

1 Introduction

Developing a sound BM is one of the key factors for achieving success in any kind of business. Many companies tend to focus on technology innovation while paying less attention to BM innovation. Chesbrough (2010, p.354) argues that "mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model". This idea is also shared by Amit and Zott (2012) who claim that managers should consider the opportunities offered by BM innovation to complement, if not substitute for, innovation in products or processes.

AXTech, a Norwegian company based in Molde, has been delivering customized heavy-duty lifting and material handling equipment since 2004. The equipment is produced in low volumes, is capital-intensive and is designed for specific needs of customers in the oil and gas industry. This form of production, where the customer order decoupling point is located at the product design stage, is called engineer-to-order (ETO) manufacturing (Olhager, 2003).

A sharp decline in oil prices (from $115 per barrel in June 2014 to under $35 at the end of February 2016 (Rogoff, 2016)) has led to a significant reduction of demand for advanced equipment from the companies operating in the oil and gas sector. Under these circumstances, in the beginning of 2015 the focal company has started to develop a new BM based on renting out of advanced lifting equipment, as an alternative to a traditional model of just selling it. By offering such a solution, the focal company tried to address the customers' reduced ability to invest money in the pricey equipment. The first piece of equipment produced by the focal company under this new BM was a lifting tower Litjkaren that was ready for market in November 2016. The tower has a lifting capacity of 25 tons, is very fast to mobilize and can be steered remotely from the focal company's headquarters in Molde. The biggest challenge the focal company faces now is, however, to reach the "right" customers and get Litjkaren to market.

The focal company's management is therefore currently paying much attention to further development and refinement of their new BM. In this respect, an Internet of Things (IoT) BM development process suggested by Slama, Puhlmann et al. (2015) as part of their "Ignite | IoT Strategy Execution" methodology was applied to re-consider the focal company's new "rental" BM.

The purpose of this paper is to describe the core elements of the IoT solution the Litjkaren's BM is based on. However, we have paid most of our attention to such elements of the IoT BM as marketing channels, customer relationships, cost structure and revenue streams, local and overall ROI of an IoT solution, as well as to nonmonetary effects of the new IoT BM.

The remainder of this paper is structured as following. In section 2, we provide a definition of the main terms and concepts used in this research. In section 3, we discuss our method. In Section 4, we present our findings and present how an IoT BM development process was adopted by the case company. Finally, in Section 5, we suggest implications for our research, outline the limitations of our study and suggest further research.

2 Theoretical background

In this chapter, we will briefly discuss the state-of-the-art literature on BM and business model innovation (BMI). Then we will take a closer look at service BMs. Further, we will discuss IoT BM development process as a part of the "Ignite | IoT Strategy Execution" methodology (Slama, Puhlmann et al., 2015). Finally, we will look at the literature discussing the challenges of getting new products and services to market, specifically as a result of BMI or development of new BM.

2.1 Business models and business model innovation

BM and BMI are studied widely and we have by no means explored all of it in this research. In the next sections, we will outline the areas we have focused on.

A recent study by Foss and Saebi (2017) shows that concepts of BM and BMI over the last 15 years have gained a lot of attention both among researchers and practitioners. Despite that attention, there is still much ambiguity with respect to what BM and BMI are.

In different sources BM is defined as either a statement, a description, a representation, an architecture, a conceptual tool or model, a structural template, a method, a framework, a pattern and a set (Zott, Amit et al., 2011). Amit and Zott (2012, p.42), for instance, define BM as a "system of interconnected and interdependent activities that determines the way the company "does business" with its customers, partners and vendors".

When it comes to BMI, Foss and Saebi (2017) identified two research streams: one research stream views BMI as a process, and another views it as an outcome. For instance, Bucherer, Eisert et al. (2012, p.184) define BMI as "a process that deliberately changes the core elements of a firm and its business logic", while Gambardella and McGahan (2010, p.263) state that BMI "occurs when a firm adopts a novel approach to commercializing its underlying assets".

Despite the increasing focus from researchers and practitioners on BM and BMI, many BMI attempts fail. One of the greatest challenges is that "business models by their very nature are designed not to change, and they become less flexible and more resistant to change as they develop over time" (Christensen, Bartman et al., 2016). They suggest that a BM consists of the following elements: value proposition, resources, processes and the profit formula. They also claim that a BM *travels a journey* through three stages: 1) creation; 2) sustaining innovation; and 3) efficiency. They conclude that the only innovations that can be performed in the existing BM *naturally* are "those that build on and improve the existing BM and accelerate its progress along the journey", and thus, in order to achieve successful BMI, the firms have to "focus on creating new BMs, rather than changing existing ones" (Christensen, Bartman et al., 2016).

Further, according to (Amit and Zott, 2012, p.44) BMI can occur in several ways: 1) "by adding novel activities" *(content);* 2) "by linking activities in novel ways" (*structure*); 3) "by changing one or more parties that perform any of the activities" (*governance*). They have also identified four major value drivers of BMs: 1) novelty ("the degree of [BMI]"); 2) lock-in ("[BM] activities that create switching costs or incentives for [BM] participants to stay"); 3) complementarities ("value-enhancing effect of interdependencies between [BM] activities"); and 4) "efficiency" (cost savings through the interconnections of the activity system) (Amit and Zott, 2012, p.45).

Despite the aforementioned ambiguity regarding what BMI is, the majority of researchers agree on that BMI is essential for any company striving for growth and better financial performance. Some even argue that BMI can be more efficient than product, process or technology innovation (Amit and Zott, 2012, Chesbrough, 2010).

2.2 Service business models/servitization

Nowadays, pushed by market conditions, competition and new customer demands, many manufacturing companies are moving towards BMs based on services (Kindström, 2010). This process is often referred to as "servitization" (Kastalli and Van Looy, 2013). Examples of services that can be offered by "product-based" companies include support and service contracts, monitoring and control services, process consulting, maintenance contracts, equipment rental etc.

Kindström (2010) analyzed aspects and challenges of companies moving towards service-based BMs. He argues that for established "product-based" companies, servitization can be considered as an evolutionary change. The challenge the companies moving towards service-based BMs often face is the need to develop both products and services simultaneously. Kindström analyzed such elements of service-based BMs as 'value proposition', 'revenue mechanisms', 'value chain', 'value network', 'competitive strategy' and 'target market', and came to conclusion that in order to shift to service-based BM, companies must change all elements of their BMs. In particular, he suggests companies moving towards service-based BM: to focus on developing relationship-building competences (with regards to both customers and suppliers); be more aware of the customer's processes (because of the need to interact with the customer in sales, delivery and post-delivery stages); to design a dynamic portfolio adaptable to needs of different customer segments; to focus on creating a service delivery infrastructure; and to focus on "developing new revenue mechanisms based on customer operations and profitability" (which may lead to cultural change in the organization) (Kindström, 2010, p.489).

Despite the growing popularity of servitization, its impact on the manufacturing firms' performance still remains an open question. Contrary to the expected economic benefits of servitization, some studies show implementation problems that can lead to the manufacturing businesses' performance decline, so-called "servitization paradox" (Kastalli and Van Looy, 2013). In order to overcome this "servitization paradox", Kastalli and Van Looy (2013) recommend service-oriented manufacturing firms the following: adopt an integrated product-service BM; implement practices that generate customer proximity; and consider necessary investments in services in order to achieve long-term profitability.

2.3 IoT business model development

Recently, proliferation of such concepts as Internet of Things (IoT), Industrial Internet, Industry 4.0 has gone viral. These concepts are interchangeably used in the context of and in connection to the new wave of disruptive changes. For manufacturing companies, the spread of IoT means first and foremost the acceleration of the shift towards integrated product-service offerings (Slama, Puhlmann et al., 2015). This transition is in line with what we have discussed in the previous section about *servitization*.

To help companies define their IoT strategies and prepare for IoT adoption, as well as to create and manage a portfolio of IoT projects, Slama, Puhlmann et al. (2015) developed a methodology called *Ignite | IoT Strategy Execution*. This methodology includes such stages as IoT opportunity identification, IoT opportunity management and Initiation. The IoT BM development is considered as a part of the IoT opportunity management stage. Here, Slama, Puhlmann et al. (2015) refer to the *IoT BM builder* developed by Bosch Software Innovations, as the *best-practice*.

The *IoT BM builder* is based on the widely used Osterwalder's *Business Model Canvas* (Osterwalder and Pigneur, 2010), and addresses such IoT-specific aspects as need for clear partner value proposition (since IoT solutions often depend on partner ecosystem) and the use of data derived from connected things and services based on top of this information (Slama, Puhlmann et al., 2015). In particular, the IoT BM builder suggests calculating the total cost of ownership (TCO) for the solution across all partners involved and "define the return model by allocating the returns among the stakeholders in a fair manner", which requires cost transparency and trust in the IoT ecosystem (Slama, Puhlmann et al., 2015, p.191). In addition, the IoT BM builder emphasizes the importance of documenting nonmonetary effects of a BM, such as new market entry, accessing new technology, coming up with new ideas and new BMs (Slama, Puhlmann et al., 2015).

This said, from practitioner's perspective, successful transformation to new, IoT BMs strongly depends on the company's ability to effectively adapt its marketing and sales strategies to their new products and services. However, the literature addressing challenges manufacturing companies face in their sales and marketing operations and customer relationship management as a result of BMI or deployment of new BMs, is scarce. This is especially noticeable with regards to service and IoT BMs.

It is evident that servitization leads to considerable transformation of how manufacturing companies sell their products and services. This involves the need for the sales teams to adjust their sales strategy. Slama, Puhlmann et al. (2015) suggest that incentive models based on upfront revenues need to be substituted by the models that support recurring revenues. In addition, marketing teams will need to utilize product usage data to carry out effective marketing campaigns for different market segments. Another driver for adjusting sales and marketing strategies of manufacturers is increasing demand for customized products, which implies that products need to be sold before they have been produced.

Baines and W. Lightfoot (2013) completed a study exploring practices and technologies successfully servitized manufacturers use in the delivery of advanced services. Among other practices, efficient customer relationships were identified as one of the factors for successful delivery of advanced services. They further point out that moving away from a "transactional approach to doing business, to one where there are strong relationships in place throughout the life-cycle of the service offering" can be seen as a "necessity for the service delivery rather than a feature of the offering" (Baines and W. Lightfoot, 2013, p.21).

3 Research objectives and methodological approach

Based on the theoretical foundations built in the previous chapter, our research aims to identify the core elements of developing an IoT BM. We have paid most of our attention to elements such as marketing channels, customer relationships, cost structure and revenue streams, local and overall ROI of an IoT solution, as well as to nonmonetary effects of the new IoT BM. Since this is an explorative form of research, a qualitative research method was chosen. Qualitative research can be done in several ways, which include ethnography, grounded theory, narrative analysis, case study analysis etc. (Guest, Namey et al., 2013). This research conducts early theory building through empirical case study. Yin (2013) states that a case study investigates a contemporary phenomenon in its natural setting and the outcome is on relevant theories generated from understanding gained through observing actual practice. We selected our case based on the opportunity to study the development process of an IoT BM and its opportunities and challenges. Data was mainly qualitative and collected through semi-structured interviews, observations and discussions. In particular, in the period between February and May of 2017 there were conducted four interviews with the CEO of

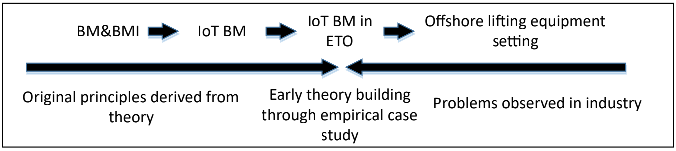

Figure 1: Methodological approach

the case company, each of which had a duration of approximately two hours. The first interview was dedicated to discussion about the strategic situation and main objectives of the focal company. In the second and the third interviews the desired properties and the technical solution of the focal company's new product (lifting tower "Litjkaren"), as well as the process of development and implementation of the new BM, were discussed. The results of these interviews were used as input in sections 4.1. and 4.2. In the last interview, the short-term costs and revenue streams, as well as the new product's long-term effects for the focal company and its customers, were discussed. The data gathered during this last interview was used in section 4.3. Secondary data such as case company's steering board documents, technical product documentation etc. were also gathered and used in sections 4.1, 4.2 and 4.3. In addition, the second author is the CEO of the case company and was part of the entire IoT BM development process. Our methodological approach as shown in Figure 1, is based on the theory of BM and BMI, and in more recent years IoT BM and follows Dubois and Gadde (2002) suggestion of systematic combining logic, where concepts and frameworks evolve during confrontation with case context and relevant literature throughout the research process. The arena for the empirical work in this paper is the ETO industry, more specifically the design and production of offshore lifting equipment.

The research question for this paper is therefore as follows: How to empirically investigate the development of an IoT BM within the specific setting of offshore lifting equipment?

3.1 Case company

In order to allow a better understanding of the case company we will give a detailed description in the following section. AXTech provides engineered and specialized heavy lifting equipment for the marine and offshore industry. The company provides the equipment on an ETO basis meaning that the equipment delivered involves project specific engineering to incorporate client, and to some extent supplier, specific functionality and performance. Fabrication, assembly and final product testing are managed through selected subcontractors worldwide.

Traditionally, since start-up in 2004, the focal company has focused on a BM that allows the company to be competitive by the four strategic standard pillars for development: Technology, Products, Organization (structure) and Market. The market (client base) has traditionally sent in Requests for Quote (RFQs) or Invitations to Tender (ITTs) that are a variety of detailed (or not so detailed) functional specifications. The bidding process can be quite comprehensive and involves substantial conceptual Front End Engineering and Design (FEED) at own risk, i.e. "no cure no pay". The actual value proposition is historically focused on a particular portfolio of products. Services offered are also targeted towards the very same installed base of products.

Typical products include winch systems, A-Frame/LARS, module handling. Core in-house technologies incorporate mechanical and structural design, advanced analysis, electric, hydraulic and automation skills in addition to particular skills within contract management, finance and fabrication. The focal company's portfolio of products has developed over years to suit specific market needs related to advanced material handling between offshore construction vessels, the sea and the seabed. The base of knowledge (within the company) is also used to explore new market opportunities. It is worth mentioning that some key personnel (owners, seniors) have a long personal track record for working within this type of industry. The history of the company must be understood with this particular background and understanding of the industry particulars.

At peak, the focal company counted some 90 employees located in Norway and Poland. As of today, the company counts less than 60 people whereas 38 people are located within Norway.

4 Results and discussion

In this chapter, to understand the background for development of a new BM solution and implementation of a new rental BM (Litjkaren) we will give a detailed description of the strategic situation and main objectives of the focal company. Further, we will present the process and results of development and implementation of the IoT, service-based BM by the case company. Finally, we will discuss the challenges as well as new opportunities connected to the focal company's transition towards the new BM.

4.1 Strategic situation and main objectives of the company

During 2014, the market changed dramatically for AXTech. From constant overload in demand, where the company struggled to get hold of sufficient engineering capacity, the amount of realistic new project potentials was drastically reduced. In addition, most of the typical clients of the company were suddenly struggling with financial liquidity. The dominant North Sea energy company launched a new cost-cutting regime to be able to cope with the changed market conditions. This regime implied 20% cost reduction by innovation, 20% by industrialization and further 20% by efficiency. The simple outcome would be to get the same services for half the cost (0.8x0.8x0.8=0.5). The focal company was confident that the company's competence and know-how was still attractive but had to be offered in a different way. By re-identifying its core technology vital for future success, the company launched a development program called Litjkaren, or by some called The Little Swinger. Litjkaren will allow the users to rent the full function of subsea module handling instead of specifying, buying and installing the equipment onto a vessel. A prime idea was to utilize whatever knowledge gained over years related both to the build and to the operational aspects of such equipment. The equipment is, due to its accurate heave compensation functionality, heavily instrumented and this allows the potential services to be further optimized. Since most of the focal company's clients faced cash-flow challenges, it was important that the equipment should be ready for use within extremely short time.

Based on a completely new BM (service proposition), the following 12 key properties were identified as shown in figure 2.

To be built by the focal company's internal, high-end standards Litjkaren should, among other things, be cost-effective, be able to operate in harsh weather conditions, have a modular structure, be transport-friendly, be quick to mobilize (installed on a vessel), be maintenance-friendly, be rugged (robust) and have as minimal environmental footprint as possible.

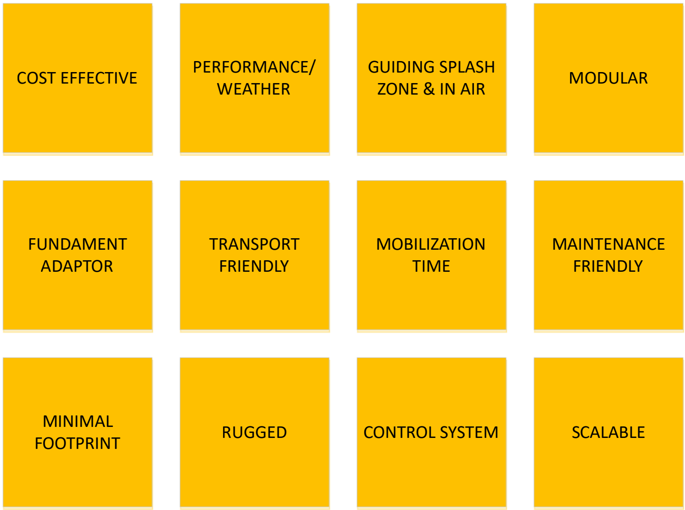

Figure 2: Litjkaren's desired properties

The desired properties became sub-targets for further enhancement of offered services and to better utilize the information provided through the applied controls system.

Services offered to include Front-End Engineering Design (FEED), vessel integration, optional support structure, installation/mobilization, operation, maintenance, de-mobilization and storage. The FEED would then incorporate the focal company's understanding of how to optimize the equipment to any type of vessel as a suitable working platform.

Due to the nature of offering this concept as a service, the focal company had to encounter a variety of vessels. The focal company also had to consider vessels without a "moon-pool" (a shaft through the bottom of a ship for lowering and raising the equipment into or from the water), which is traditionally used for subsea module handling and to incorporate features that allow for proper guiding at the vessel's side.

Remote diagnostics and operation were also to be offered as various apps or add-ons to the controls system.

Another feature that was discussed was the focal company's ability to enhance the complete operation by tapping into the vessel's existing Dynamic Positioning (DP) system and by that further enhance operational properties. The focal company has previously developed advanced in-house software that provides detailed understanding of a vessel's property (behavior) in combination with such specialized equipment installed. This allows the focal company to optimize the operation towards specific needs. For instance, the vessel owner may ask "Can I recover a 20t module in such defined sea condition?" The focal company's system will then optimize not only the equipment, but also the vessel (heading, draft etc.) for the conditions given and to provide a clear answer. Also by accumulative knowledge the focal company may also suggest for the vessel owner to optimize the vessel for further enhancement (like roll/pitch dampening system etc.)

The actual equipment in discussion is a lifting tower designed for safe handling of subsea modules and tools between a vessel operation in open sea (harsh weather conditions) and the seabed (figure 3).

This incorporates heave compensated winch systems in addition to various means of guides to secure the object from any kind of operational damage. The tower size and capacity are defined by a careful evaluation of available common modules used for such application.

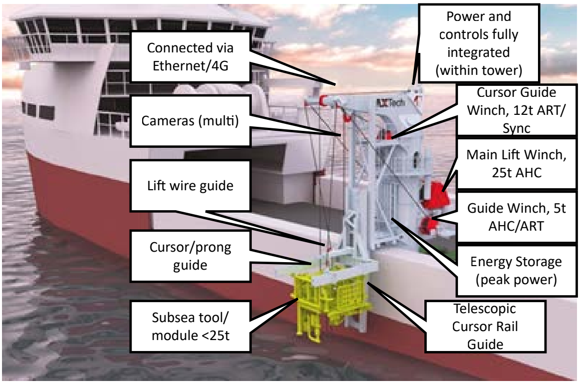

Figure 3: Litjkaren: technical solution

Layered architecture of digital technology consists of four layers: devices, networks, services and contents (Yoo, Henfridsson et al., 2010). Below we briefly characterize each of these layers in Litjkaren's architecture.

Device Layer: Sensors/Equipment. The equipment is fully instrumented to the extent that all relevant parameters are fully monitored and controlled. Access to relevant data is available both through local application servers and by remote servers via satellite network or 4G communication links.

Network Layer: 4G/Ethernet

Service Layer: Knowledge base (people), in-house developed tools for optimized operational properties.

Content Layer: Analysis, optimized operations data, remote operation concept (app), preventive and corrective maintenance system.

4.2 Developing and Implementing the IoT BM

For the development of the product, it was necessary to get a full overview of the BM and look for both internal improvements and for potential new business based on the fact that the equipment now was fully connected.

Internal Improvements. A core element for the design was to implement and improve on existing solutions for improved maintenance. As the plan was to rent out the equipment, the focal company needed to secure an improved Overall Equipment Effectiveness (OEE). Examples of such improvements are remote monitoring and efficient maintenance programs.

In addition, by avoiding expensive and, to some extent, excessive client specifications the focal company was able to enhance overall quality by focusing purely on function, reliability and connectivity. Overall target was to gain quality improvements.

New business. Through IoT opportunity analysis there were also evaluated new business opportunities that could be developed within this project. The project provided new business opportunities both as a product-centric BM but also as a new service-centric BM. The idea was to focus on the product itself (fully optimized) and at the same time allow this particular product to form a central part of the services offered. Revenue would then be generated from not just the actual rental but also the substantial amount of added services needed. Examples of such additional services are wire spooling and condition monitoring non-destructive testing (NDT) services.

The revised BM can be described as outlined in the three phases of the Innovation Project Canvas with Asset Integration Architecture (AIA) developed by Five I's Innovation Management GmbH (Slama, Puhlmann et al., 2015, p.188). The first phase is to develop the actual value proposition with a repeating review of the client, client needs, market trends and competition. For the focal company, this incorporated an evaluation of competitive designs and how to secure that the final concept could provide a competitive edge not only by functionality but also by net investment (cost).

In the second phase, there is an evaluation of the actual solutions offered. For the focal company, it was important to offer the full comprehensive service, like a payment per lift/operation as this would allow also new clients with less capacity to incorporate this function as a part of their own ambition. By doing this, the focal company could enter a position in which the more senior clients would regard the concept also as a threat to their own business, because operators of smaller and less expensive vessels would now be able to offer advanced subsea lifting without the need to either invest in or operate the actual equipment.

This allows the services offered to be differentiated and adjusted towards each specific client. The concept of remote operation is something that will enhance the value proposition significantly and this subject is currently jointly discussed with relevant Remotely Operated Vehicle (ROV) services providers. The third step is to move forward on the development of the services to be offered.

Marketing and sales of such a comprehensive and highly technical service package is something that requires careful planning and continued efforts over time. The focal company's method is built on the well-used word of trust. As most of this type of equipment is normally presented as ideas on drawings and storyboards, the focal company was eager to present the very real thing. Key clients were invited either individually or in groups so that all operational properties could be demonstrated. Another important method for telling the story is to attend technological conferences and have papers presented. The focal company strongly believes in building trust by personal attendance but in this case, a digital marketing strategy was also formed to make sure the concept made known to the public. LinkedIn, Facebook and electronic white-papers were all part of this strategy.

4.3 Challenges and Opportunities

In Figures 4 and 5 below, we briefly analyze Litjkaren's short-term costs and revenue streams ("local ROI"), as well as the solution's long-term effects for the focal company and its customers ("overall IoT business case") as suggested by Slama, Puhlmann et al. (2015).

When launching Litjkaren, the focal company's management consciously accepted high risk of having negative "local ROI" of the new BM in the short run. This was due to high upfront capital expenditure (CAPEX) in both hardware and software and operating expenditure (OPEX) connected to maintenance, repair and operations of Litjkaren – in the situation of absence of specific customers. Once rented out, it was planned that Litjkaren would generate both upfront revenues such as payment per mobilization/integration/demobilization, as well as recurring revenues such as daily rent, service and remote operations payments (Figure 4).

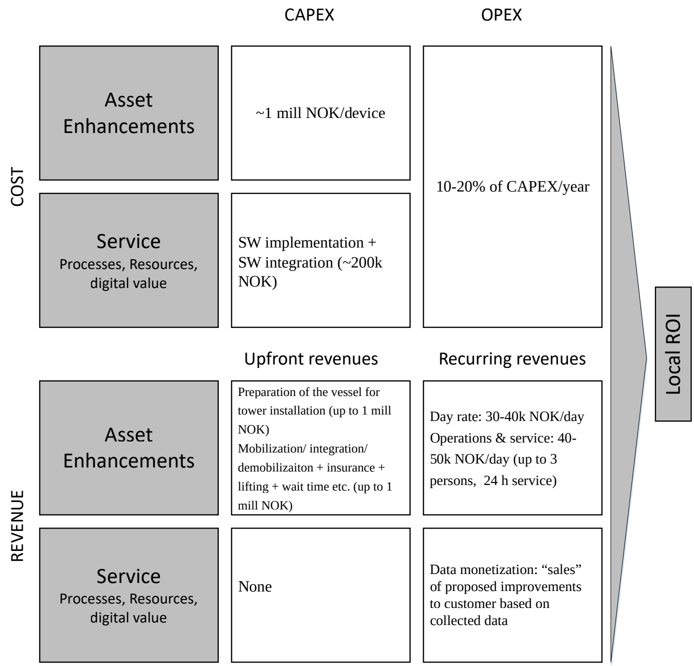

Figure 4: Local IoT solution ROI,Litjkaren (based on (Slama, Puhlmann et al., 2015))

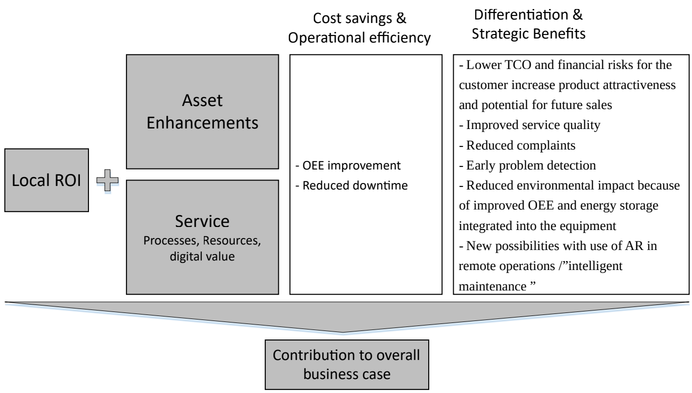

Figure 5: Overall IoT business case, Litjkaren (based on (Slama, Puhlmann et al., 2015))

From the overall business case perspective, in the long run, the new solution was supposed to lead to substantial strategic benefits for the focal company (Figure 5). New rental BM would mean lower total customer's costs of ownership (TCO) of the solution and would decrease customer's financial risks connected to ownership of the pricey equipment. The new solution would also provide for early problem detection and thus help increase overall equipment effectiveness (OEE). In addition, development of Litjkaren has led to a new idea for enhancing maintainability by implementing Augmented Reality (AR) technology. Since the tower is designed to be maintained with a minimum amount of personnel, the focal company needs to ensure specialist assistance and guidance on rather complicated machinery and controls. An internal AR project is now formally initiated to explore these opportunities as something that can add up to the value proposed. At start, the focal company could not see the ROI for this investment, but as the technology becomes more practical in use, the company now assumes that also clients are more willing to pay for such services.

5 Closing remarks

Despite the ambiguity regarding what BMI is, the majority of researchers agree on that BMI is essential for any company striving for growth and better financial performance. In recent years, BMs based on services have gained a big popularity (and many have proven successful) among many manufacturing companies. A powerful push to the manufacturing companies' transition towards service-based BMs, or so-called "servitization", was given by the rapid development of the IoT.

In response to new market conditions and in anticipation of new customer demands, the focal company started developing a product based on a completely new, service-based, IoT BM.

At the point as this research was ended, Litjkaren was not assigned for any particular work. The market situation seems to be still at a stage where the existing fleet of equipment/vessels has covered the needs of such subsea projects. It is a fact that most of this work has been performed with significantly larger equipment than strictly needed. Over time, the focal company is confident that there will be a market for smaller light-weight systems that can be rented for a fraction of the investment price needed when a full-size tower is integrated on a vessel.

For the focal company this project has been a good opportunity to further explore new business potentials and to enhance the applied technology. Exploring the business of servitization has introduced new thinking on how to enhance the value proposed.

Finally, how to promote BMI would appear to be critical business management skills. The authors regard the measurement of effectiveness of BMI to be dependent on empirical observation and more similar research is needed. As this reseach is limited to a single case, the research team is currently exploring the possibilities to re-apply the suggested concept of developing and implementing the IoT BM to several companies supplying advanced offshore equipment.

Acknowledgements

The authors would like to express their appreciation to the Norwegian Research Council as well as the case company participated in this research cooperation. Without their contribution, this research would have never materialized.

References

Amit, R. and C. Zott (2012). “Creating value through business model innovation”. In: *MIT Sloan Management Review* 53.3, p. 41.

Baines, T. and H. W. Lightfoot (2013). “Servitization of the manufacturing firm: Exploring the operations practices and technologies that deliver advanced services”. In: *International Journal of Operations & Production Management* 34.1, pp. 2–35.

Bucherer, E., U. Eisert, and O. Gassmann (2012). “Towards systematic business model innovation: lessons from product innovation management”. In: *Creativity and Innovation Management* 21.2, pp. 183–198.

Chesbrough, H. (2010). “Business model innovation: opportunities and barriers”. In: *Long range planning* 43.2, pp. 354–363.

Christensen, C. M., T. Bartman, and D. Van Bever (2016). “The hard truth about business model innovation”. In: *MIT Sloan Management Review* 58.1, p. 31.

Dubois, A. and L.-E. Gadde (2002). “Systematic combining: an abductive approach to case research”. In: *Journal of business research* 55.7, pp. 553–560.

Foss, N. J. and T. Saebi (2017). “Fifteen Years of Research on Business Model Innovation: How Far Have We Come, and Where Should We Go?” In: *Journal of Management* 43.1, pp. 200–227.

Gambardella, A. and A. M. McGahan (2010). “Business-model innovation: General purpose technologies and their implications for industry structure”. In: *Long range planning* 43.2, pp. 262–271.

Guest, G., E. E. Namey, and M. L. Mitchell (2013). “Qualitative research: Defining and designing”. In: *Collecting Qualitative Data*, pp. 1–40.

Kastalli, I. V. and B. Van Looy (2013). “Servitization: Disentangling the impact of service business model innovation on manufacturing firm performance”. In: *Journal of Operations Management* 31.4, pp. 169–180.

Kindström, D. (2010). “Towards a service-based business model–Key aspects for future competitive advantage”. In: *European Management Journal* 28.6, pp. 479–490.

Olhager, J. (2003). “Strategic positioning of the order penetration point”. In: *International journal of production economics* 85.3, pp. 319–329.

Osterwalder, A. and Y. Pigneur (2010). *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Rogoff, K. (2016). Web Page. https://www.weforum.org/agenda/2016/03/what-s-behind-the-drop-in-oil-prices/.

Slama, D., F. Puhlmann, J. Morrish, and R. M. Bhatnagar (2015). *Enterprise IoT: Strategies and Best Practices for Connected Products and Services*. ” O’Reilly Media, Inc.”

Yin, R. K. (2013). *Case study research: Design and methods*. Sage publications.

Yoo, Y., O. Henfridsson, and K. Lyytinen (2010). “Research commentary—the new organizing logic of digital innovation: an agenda for information systems research”. In: *Information systems research* 21.4, pp. 724–735.

Zott, C., R. Amit, and L. Massa (2011). “The business model: recent developments and future research”. In: *Journal of management* 37.4, pp. 1019–1042.

Supply Chain Flexibility and SMEs Internationalization. A Conceptual Framework

Sylvia Mercedes Novillo Villegas[1], Hans–Dietrich Haasis[1]

1 – University of Bremen

This paper has the aim of analyzing the relationship of logistics capabilities and supply chain flexibility (SCF) as part of small and medium-sized enterprises (SMEs) internationalization strategy through a review of relevant research in these areas. This review will constitute the foundation for developing an integrative conceptual framework to understand the relationship. An integrative literature review in internationalization approaches, SCF and logistics capabilities from 2006 through 2016 was conducted. The analysis of an extract from this literature review is presented to identify the key elements that contribute to the SMEs' flexibility as a strategy to achieve their internationalization goals. The role that logistics capabilities play in achieving SCF as part of SMEs internationalization strategies has not been analyzed in literature from an integrative conceptual perspective. Further, the areas of research were conducted mostly in large firms from developed markets. A multi-disciplinary approach is used in this research to address this gap. As such, this paper is the first on analyzing the relationship between the areas of interest. This constitutes the initial phase of building a theory on the relationship between SMEs internationalization, SCF, and logistics capabilities. Further research will be necessary to empirically test the conceptualized relationships in both developed and emerging markets. This paper also presents managerial implications. The relationships between the presented areas contribute to a better understanding of the influence of logistic capabilities regarding SMEs flexibility in a supply chain context. This will lead to improving the SMEs' innovation and logistics management while designing internationalization strategies.

Keywords: maritime security; illicit trade; detection architecture; discrete event simulation

1 Introduction

Internationalization is a high-risk strategy that any firm can undertake due to the complexity and uncertainty of international environments. Nevertheless not embracing this strategy connotes to the firms a major disadvantage in relation to their competitors who have an international orientation (Leonidou, 2004). Furthermore, internationalized companies have shown a better capacity to innovate and adapt to the fluctuations of the demand (Johanson and Vahlne, 2009). In addition, the business scenario has switched from firms competing as independent entities to a supply chain competing scenario (Christopher, 2000). Small and medium-sized enterprises (SMEs) cope with many limitations due to poor capabilities (e.g. innovativeness) and lack of resources (e.g. production capacity) though they are recognized for being flexible, which can lead to a faster response and to have closer relationships with customers and suppliers (Singh, Garg and Deshmukh, 2008; Ismail, Poolton and Sharifi, 2011). Singh, Garg and Deshmukh (2008) argued that it is necessary to assume a holistic approach in order to sustain SMEs competitiveness, as the firms must assess their resources, procedures, and performance regarding the referents in the industry.

In a dynamic business environment, with the aim of developing a competitive advantage, companies have to synchronize their strategies, resources, capabilities, and operations, with suppliers to respond positively to customers' demand and consequently together achieve higher levels of flexibility beyond individual firms (Gligor, 2014). Hence, firms adopting supply chain flexibility (SCF) strategies will have an edge over their competitors (Singh and Acharya, 2013). Moreover, in a supply chain scenario, companies have to unify, integrate and synchronize their own logistics capabilities within their network partners in order to compete with firms outside their supply chain (Gligor, 2014). Gligor and Holcomb (2012) argued that supply chain agility is prompted by joining together logistics capabilities at a network level. Mentzer, Soonhong and Bobbitt (2004) grounded the statement that an integral element of the management of the supply chain is logistics; therefore logistics capabilities constitute a key element for developing supply chain broad capabilities. Further, from an empirical study, Mandal (2016) found that logistics capabilities impact positively on SFC which in return affects positively the performance of the supply chain.

There is an extensive body of literature regarding the influence of logistics capabilities in achieving sustainable competitive advantage regarding a supply chain context (Mentzer, Soonhong and Bobbitt, 2004; Stank, Davis and Fugate, 2005;

Esper, Fugate and Davis-Sramek, 2007; Gligor and Holcomb, 2012; Gligor, 2014; Mandal, 2016). With respect to the research conducted about SMEs on these fields, Gelinas and Bigras (2004) examined the features and characteristics of SMEs in order to recognize their impact on the integration of logistics. They found that in some aspects, SMEs appeared "dynamically suited to integration". The flexibility of the SME, the growth of the entrepreneur and its sustainability goals, the simplified decision-making processes, the closeness of operational and organizational levels were categorized as well-suited with integrated logistics. By contrast, the authors categorized as unfavorable the "firms' focus on effectiveness rather than efficiency, their tendency to underutilize information technologies, and their short-term strategic planning" (p.276). In addition, previous research on these three areas of interest was conducted mostly in large firms from developed markets (Gelinas and Bigras, 2004; Verdú-Jover, Lloréns-Montes and García-Morales, 2006; Mellat-Parast and Spillan, 2014; Felzensztein et al., 2015; Zhang et al., 2014).

In the regard of SMEs internationalization, the role of logistics capabilities in achieving SCF as a competitive advantage has not been analyzed in the research. This gap highlights the necessity of an integrative conceptual frame with the aim to understand the relationship. Thus, it is necessary the development of an integrative framework to unify the areas under study. This paper presents the initial stage of developing an integrative conceptual framework through an integrative literature review.

2 Methodology

An integrative literature review was conducted to establish a comprehensive outlook to define the relationship of logistics capabilities in gaining SCF when designing internationalization strategies for SMEs.

The first section introduced the motivation for this work, the areas of interest (i.e. SMEs' internationalization approaches, SCF and logistics capabilities) which have led to the problem formulation. The review of literature related to the areas of interest from 2006 through 2016 was conducted. Section 3 presents a quick summary of the literature reviewed in internationalization theories (to better understand the drivers and factors that influence SMEs internationalization); SCF (to establish the characteristics and elements of SCF as a competitive strategy); and logistics capabilities (to provide the elements that influence SCF and SMEs internationalization). In section 4, the literature review is analyzed and interpreted to integrate a conceptual framework. The last section includes the theoretical conclusions and managerial implications.

3 Literature Review

3.1 SMEs Internationalization

Leonidou (2004, p. 281) defined firms' expansion as "the firms' ability to initiate, to develop, or to sustain business operations in overseas markets". Three approaches of internationalization (i.e. stage approach, network approach and entrepreneur approach) are presented to formulate an integrative framework regarding the phenomenon of SMEs internationalization.

3.1.1 Stage Approach

To the authors of this approach, firms' internationalization is considered as an "evolutionary process" where firms gradually increment their involvement in international markets going from one stage of internationalization to the next (Cavusgil, 1984, p.196). Firms should select the optimal entry mode to foreign markets by evaluating their risks, market constraints, and their own resources. This approach has two main subdivisions: the innovation-related internationalization model (I-model) (Bilkey and Tesar, 1977; Cavusgil, 1980) and the Uppsala model (Johanson and Vahlne, 1977).

The innovation-related internationalization model (I-model) compares the process of firms' internationalization with the stages of adoption for a new product. Under this approach, each internationalization stage is studied as an innovation stage for the firm. On the other hand, Johanson and Vahlne (1977) developed an internationalization model, known as the Uppsala model, regarding the learning curve of a firm. This model is grounded on two main components: the market knowledge (including operations and markets overseas), and the market commitment, i.e. the number of committed resources to foreign markets.

Firm's current activities and experience of operations in foreign markets contribute to structure its market knowledge. The gained knowledge influences the level of commitment with the foreign market according to the decisions made and the subsequent activities that result from those decisions as well as the number of committed resources. Johanson and Vahlne (1977, p.23) characterized the approach as dynamic since internationalization "is the product of a series of incremental decisions" which lead from one level of commitment to the next stimulating more learning.

This model also introduced the notion of "psychic distance" defined as "the sum of factors preventing the flow of information from and to the market" (Johanson and Vahlne, 1977, p.24). Culture and language dissimilarities, the degree of development in the industry, among others factors affect the way to receive and transfer information in foreign markets. Thus the diminution of the psychic distance through an integrated flow of information might enhance the firm' access to more geographically distant targeted markets.

3.1.2 Network Approach

Johanson and Vahlne (1990) introduced a business network approach. The authors stated that firm's internationalization is affected by the business relationships in the networks of foreign markets. The argument is that the existing network relationships affect firm's decision to access a specific market and the choice of the entry mode. Further, Johanson and Vahlne (2009) analyzed the drivers and the modes of internationalization by mobilizing internal and inter- organizational relations. They included the "recognition of opportunities" as part of the market knowledge, due to the importance of this capability as it prompts the internationalization process. This capability is developed by creating financial, market and technological links with other network partners and increases progressively its operations from local markets to foreign markets. The authors set the second state variable, "network position", due to their assumption that firm's internationalization process is determined by the position and partnership of the firm within a network. Relationships depend on particular levels of knowledge, trust, and commitment which vary from one partner to another.

For future references in this work, the supply chain will be the network scenario of analysis (Stevenson and Spring, 2007).

3.1.3 International Entrepreneurship

The international entrepreneurship approach emerged from entrepreneurship literature when it comes to understanding entrepreneurial processes to explain the internationalization of a firm (Freiling and Schelhowe, 2014). An international entrepreneur is the result of the combination of a proactive, innovative, and risk-taking behavior which leads to cross national borders by creating value in the firm to establish business operations in foreign markets (McDougall and Oviatt, 2000). Therefore, three key elements are identified in this approach: innovativeness, proactiveness and risk-taking (Oviatt and McDougall, 2005). The proactive behavior of firms leads them to take risky measures to overcome psychic distance through innovating their products, production processes, marketing processes, sales and service support with the aim of satisfying the requirements of a multicultural customer base. Innovativeness is firm's capability to "promote new and creative ideas, products, and processes designed to service the market" (Felzensztein et al., 2015, p.149). This implies that the more diverse are the target markets, the more innovative the firm might need to be in order to develop successful strategies for those markets. Proactiveness refers to the firm's ability to acquire, use, and exchange market knowledge in a way that firm is able to commit resource in a marketplace. Internationalization demands a higher level of resources (i.e. production, financial, human) and capabilities that might be acquired through the market knowledge and proactive behavior. Thus, the firm is stimulated to undertake risky decisions. They also need the capability to learn from their competitors and their international network in order to identify opportunities, make more risky decisions and work better with customers (Freiling and Schelhowe, 2014).

3.2 Supply Chain Flexibility (SFC)

3.2.1 Defining the Concept

The actual business environment is highly dynamic and competitive as a result of the introduction of new technologies and the sophistication of customers' demand, who require customized product in shorter lead times. Therefore, firms have to deal with more complex scenarios filled with uncertainties and turbulences (Stevenson and Spring, 2007). Considering these circumstances, flexibility emerges as a strategic capability to effectively adapt to dynamic environments.

Flexibility is the capacity to shift or adapt with slight punishment in terms of performance, cost, time or effort (Upton, 1994). Furthermore, for achieving the flexibility required to add value to the customers, suppliers and distribution channels as well as to the organization, the firm has to act beyond its internal domain (Martínez Sánchez and Pérez Pérez, 2005; Kumar et al., 2006).

The study of SFC has its roots in the literature in manufacturing flexibility and arose in the decades of 1980 and 1990 (Slack, 1983; Sethi and Sethi, 1990; Koste and Mal-hotra, 1999). Early studies demonstrated that flexibility impacts positively on the performance of the firm. The literature on manufacturing flexibility focuses mainly on the physical resources and the internal performance of a firm thus is not sufficient to the complexity and dynamics of supply chains in which firms are embedded (Lummus, Duclos and Vokurka, 2003). Moreover, supply chain operates as a complex system, where the performance of every part involved affects the entire system performance. Consequently, the flexibility of each network partner and their interrelationship result in the flexibility of the entire supply chain (Duclos, Vokurka and Lummus, 2003).

Authors and practitioners have different perceptions about the concept of flexibility. Lee (2004) explained the flexible capability of a firm through three different elements, i.e. adaptability, alignment, and agility. Supply chain adaptability is the capability to set the network design to meet structural changes upstream or downstream, adjust the strategies of the supply network, and design products and services. Alignment is the capability to generate incentives between the participants within the network for a better overall performance. Agility is the capacity to act quickly to short-term fluctuations upstream or downstream and manage external disturbances smoothly.

Stevenson and Spring (2007) stated that SCF is the ability to generate a quick response to different disruptions in demand and supply along with modifications in other environmental parameters e.g. capacity limits, lead-time, and exchange rate. Kumar et al. (2006, p.305) defined SCF as “the ability of supply chain partners to restructure their operations, align their strategies, and share the responsibility to respond rapidly to customers’ demand at each link of the chain, to produce a variety of products in the quantities, costs, and qualities that customers expect, while still maintaining high performance”.

Lummus, Duclos and Vokurka (2003) identified the components of SCF (i.e. operations systems, supply network, logistics processes, information systems, and organizational design) and also the potential features of these components that produce flexibility in the supply chain. Further, the authors introduced a supply chain model regarding the identified components which might lead to customer satisfaction when working effectively in a coordinated and collaborative manner. In addition, Kumar et al. (2006) introduced an integrative framework for the implementation and management of SCF. The framework includes three stages, i.e. required flexibility identification procedure; implementing and sharing responsibilities; and feedback and monitoring.

Stevenson and Spring (2007) highlighted some characteristics of flexibility. They argued that this capability is always present in some degree. Moreover, it is also a multi-dimensional and complex concept, which is difficult to measure, challenging to gain and hard to imitate. The authors developed a hierarchical taxonomy of SCF based on the different components of manufacturing flexibility. Moreover, some dimensions of flexibility influence others, e.g. supply chain design flexibility is influenced by sourcing flexibility (Gosling, Purvis and Naim, 2010).

3.2.2 Drivers and Analysis

It is important to understand the drivers of SCF to establish the role of logistics capabilities in accomplishing SCF strategies as a sustainable competitive advantage for SMEs internationalization. Flexibility drivers are situation or factors that fashion the need for flexibility. At the same time, each driver is associated with some kind of uncertainty, e.g. external downstream driver for SFC is the customer who is responsible for demand uncertainty and likewise external upstream driver is the supplier, who is responsible for sourcing uncertainty that may drive the focal firm to maintain a pool of suppliers (Tiwari, Tiwari and Samuel, 2015). Kumar, Shankar and Yadav (2008) established mutual relationships and interactions among the flexibility enablers through the development of an interpretive structure model. A supply chain, characterized by important levels of process and information integration, collaborative relationships, and responsiveness flexibility, will be able to respond to the different sources of uncertainty (Gligor and Holcomb, 2012). The impact that integration generates in achieving SCF is a fundamental theme in the research. The integrated flexible supply chain constitutes a competitive strategy to develop a domestic and overseas leadership in a dynamic environment of fluctuating customer demands (Kumar, Shankar and Yadav, 2008).

3.3 Logistics Capabilities

Logistics capabilities are used to align, combine, adapt, and reorganize functional competences, resources and structural skills to improve the overall performance (Gligor and Holcomb, 2012). Capabilities are the combination of dynamic routines and procedures which show how the resources are structured, applied and synchronized with the environment (Stank, Davis and Fugate, 2005) in order ”to achieve superior performance and sustained competitive advantage over competitors” (Morash, Droge and Vickery; 1996, p.1). They also constitute complex sets of knowledge and skills, which determine the firm’s capacity of general ability and efficiency. Moreover, studies have demonstrated that logistics capabilities constitute a competitive advantage to the firm. Though the concepts of supply chain management and logistics are related, there are individual differences. Logistics is in charge of planning, executing, and monitoring the effective and efficient flow and storing of resources, information, and services associated with the processes of the supply chain from the sourcing place to the consumption place with the aim of fulfilling customer demands (Mentzer et al., 2001). In contrast, supply chain management is the set of related activities and resources of each supply chain partner which might be considered as logistics systems integrated into a network. The success of a supply chain depends on a high degree of the capabilities of individual logistics systems, particularly for quality- and time-based competition (Duclos, Vokurka and Lummus, 2003).

Mentzer, Soonhong and Bobbitt (2004) studied the strategic relationship of logistics and its capabilities within the frame of firm theories. The authors presented a ”unified theory of logistics”, that includes the conceptualization of logistics capabilities which result in a competitive advantage. These logistics capabilities are categorized into four broad groups, i.e. logistics quality and customer service (capabilities of demand-management interface); low supply and distribution cost (capabilities of supply-management interface); information technology and information sharing (information-management capabilities); and interior and exterior coordination capabilities.

Esper, Fugate and Davis-Sramek (2007) studied how firms develop and acquire their logistics capabilities and the way they are used to gain a sustainable competitive advantage. The authors highlighted that the literature referred to the logistics capabilities mainly included integration capabilities, demand management capabilities, supply management capabilities, measurement capabilities (the degree to which firms monitor internal and external processes and the achievement of strategies), and information exchange capabilities. Three fundamental aspects are included into the classification of logistics capabilities, i.e. effectiveness, efficiency, and differentiation. Effectiveness is the result of collaborative efforts through integration capabilities. Supply-management capabilities stimulate the firm to undertake efficiency while demand-management capabilities enable differentiation strategies. Information exchange is a requirement to accomplish the expected internal and external results that have to be measured (Gligor and Holcomb, 2012).

4 Analysis and Integration of the Concepts

It is necessary the understanding of the relationship between the drivers of flexibility, logistics capabilities as a source of flexibility and SCF for developing the present conceptual framework. It will provide the indispensable elements to analyze the role of logistics capabilities in accomplishing SCF strategies for SMEs' internationalization. A synthesis of the literature regarding the relationship between these three areas is presented in figure 1.

Logistics creates advantages such as the customer value enhancement, the productivity assessment, and functional effectiveness. One of the unique attributes of logistics is the active coordination with inside- and outside- functions of the firm. Therefore logistics capabilities have two dimensions, i.e. internal and external (Gligor and Holcomb, 2012). The internal dimension works directly with other functions and competences to organize, integrate and design cross-functional processes inside the firm (Morash, Droge and Vickery, 1996). The external dimension expands logistics outside the company boundaries to link suppliers and customers. As strategy, logistics generates the capability to synchronize and incorporate interdependent processes regarding the flow of goods, services and related information across major functional areas both materials management and physical distribution. Through this unique attribute from logistics, the firm can generate a supply chain capability by integrating processes, resources, operational and systems interfaces to maintain operational coordination while decreasing redundancy (Mentzer, Soonhong and Bobbitt, 2004). Moreover, logistics capabilities enable the firm to generate flexibility in the supply chain to cope up with the uncertainties of nowadays business environment.

Five relational functions to manage SMEs internationalization (i.e. market management, knowledge management, network management, innovation manage-

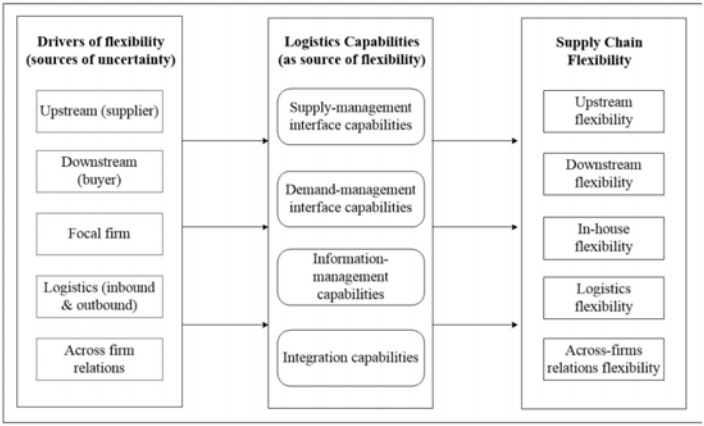

Figure 1: Relationship between drivers of flexibility, logistics capabilities and SCF

ment, and resource management) are identified from the literature review on internationalization. For the purpose of this work, a relational function for internationalization refers to the management of activities to set the internationalization strategies of a firm and coordinate its internal functions as well as the relationships and efforts within its business network. The firm will be able to accomplish internationalization objectives through the effective use of the available resources, functional competences, and organizational abilities within the supply chain.

The functions of market management and knowledge management set the main internationalization strategy that the firm will adopt through the analysis of the body of knowledge gained from the experiences overseas and the information flow within its supply chain. The recognition of opportunities is one of the main capabilities related to these functions as it prompts the design, adoption or modification of internationalization strategies through the valuation of future opportunities in foreign markets (e.g. selecting the entry mode). The stage approach identified the market knowledge as a key factor to succeed overseas (Johanson and Vahlne, 1977). Moreover, it highlights the influence of internal and external drivers of internationalization and stresses the need for a different exporting strategy according to each degree of internationalization and the commitment with foreign markets (Johanson and Vahlne, 2009). Thus, the development of information exchange is essential for managing, analyzing, acquiring, storing, and distributing strategic and tactical information in the interior as well as with the exterior of the firm (Mentzer, Soonhong and Bobbitt, 2004). Further, a sustainable competitive advantage is the result of organizational learning (Mentzer, Soonhong and Bobbitt, 2004) and SCF (Singh and Acharya, 2013) among other elements. Information exchange prompts collective learning processes about organizing manufacturing abilities and the incorporation of technology streams (Mentzer, Soonhong and Bobbitt, 2004). SCF, as strategy improves the ability to respond to fluctuations in the environment. Aligning information systems enables firms to satisfy changing information requirements within the supply chain in order to accomplish strategic goals and identify business opportunities (Singh and Acharya, 2013).

Through the network management, the firm sets its internationalization strategies regarding its relationships within the supply chain. Further, this function depends on the firm' networking capabilities as the internationalization process depends on the network relationships of the firm (Johanson and Vahlne, 2009). In addition, highly specialized and transferable resources (except the most strategic ones) are appreciated in a networking firm, but the full use of these resources will depend on the firm' networking capabilities. Pihkala, Varamaki and Vesalainen (1999, p.340) defined networking capabilities as the "abilities such as communicating skills, cooperativeness, ability to share a vision, trust, ability to act as a network broker, customer orientation, ability to use market information, knowledge of co-operative arrangements and market orientation". In contrast to the case of born global, if the firm has poor of these capabilities, the internationalization process will be in an incremental and progressive way (Felzensztein et al., 2015). In addition, this function is responsible for the process of constructing resources and competences as it represents the main source of exchange, and opportunities as well as prompts innovation and creativity (Johanson and Vahlne, 2009). The internationalization- and competitiveness' degree of the network influences the internationalization- and competitiveness' degree of the firm. Consequently, the relationships within the network stimulate the process of firm' internationalization (Johanson and Vahlne, 2009). Gligor (2014, p.586) suggested that firms aspiring to integrate supply chain strategies must have supply chain orientation and "must develop firm-level strategies consistent with their supply chain orientation and their objective of competing through agile response". Firms that develop flexible strategies will recognize the importance of integrating demand and supply, along with process flexibility. Thus, flexibility in the supply chain needs alignment between each supply chain partners and it is accomplished through information sharing (Singh and Acharya, 2013). Furthermore, logistics capabilities enable the development of differentiation strategies of products and service through value-added activities. Mandal (2016) found that trust, commitment, power, and reciprocity the socio-exchange attributes have a positive and direct impact on integrated logistics capabilities that are also positively related to the enhancement of the supply chain performance. Trust and commitment are explicit elements of the network approach (Johanson and Vahlne, 2009) which implies a learning process embedded between internationalization, the development of logistics capabilities to achieve SCF.

Innovation management refers to firm's usage of resources and competences, knowledge, and risk-taking and proactive behavior to create value and differentiation through the transnational coordination of the firm business network. The international entrepreneurship approach explains firms' internationalization through innovativeness, and risk-taking and proactiveness (Felzensztein et al., 2015). Additionally, superior levels of trust, knowledge, and commitment lead to efficient and innovative processes (Johanson and Vahlne, 2009). Creating supply chain flexibility is one method to face the uncertainty of demand, especially in innovative categories of products (e.g. electronic devices) or mass customized products (Stevenson and Spring, 2007). Moreover, firms are forced to plan the strategic use of their resources and manage their innovation regarding the customer demand and competitors behavior (Lummus, Duclos and Vokurka, 2003). Further, "value chain flexibility reflects the current state of embedding process innovation into the supply chain operations and being proactive in managing supply-demand fulfillment" (Hock Soon and Mohamed Udin, 2011, p.507). For developing innovation, it is necessary to determine the functional responsibilities across the supply chain in a rapid and effective way. High levels of logistics capabilities within the supply chain partners might increase the development of new products, services and processes to reach competitive differentiation (Esper, Fugate and Davis-Sramek, 2007).

Last, resource management sets appropriate strategies to acquire, develop, adjust and coordinate the sourcing and use of resources along firm's business network. Johanson & Vahlne (2009) stated that the adjustment of resources and the coordination of activities within the "outsidership" are necessary. Thus, the networks are fundamental to enable SMEs the development of their limited resources (Pihkala, Varamaki and Vesalainen, 1999). The acquisition and development of logistics capabilities might influence the generation of sustainable internationalization strategies, since they facilitate the total cost reduction in supply chain operations, and enable postponement, modularization, and standardization strategies (Esper, Fugate and Davis-Sramek, 2007). Moreover, through the development of logistics capabilities, implementing SCF strategies will mean a competitive advantage as the firm enhances its ability for shipping and receiving goods rapidly and efficiently as sources of supply and customers fluctuate (Stevenson and Spring, 2007; Singh and Acharya, 2013).

5 Conclusions and Future Research

From the multidisciplinary literature review, it is concluded that internationalization is a complex process. For achieving a competitive and sustainable advantage in foreign markets, the role of decision makers is to select and develop effective resources and competences. The market knowledge, network relationships, value system, and an entrepreneur behavior are indispensable elements in SMEs' internationalization. Stank, Davis and Fugate (2005, p.29) stated "creating and sustaining competitive advantage is an important part of the strategic planning process". A firm's strategy built up regarding external factor from the environment will drive the process to develop a structural and operational organization. "Firms that have properly aligned strategy with structure are expected to perform better than competitors that lack the same degree of strategic fit". As the competition scenario shifted from single firms' competition to supply chains' competition, SMEs have to implement a supply chain orientation, particularly to face international dynamic markets. This might lead to accomplish a competitive and sustainable advantage. SMEs in a supply chain have to coordinate and incorporate logistics capabilities as individual firms with their supply chain partners to compete with enterprises outside their supply chain. It is also necessary to mention that the main research of the areas of interest is conducted in developed and industrialized markets. There are only a few studies analyzing the impact of internationalization of SMEs from emerging markets, particularly in Latin American countries.

This research presents the first phase in building an integrative conceptual framework to integrate and describe the relationship between the three areas of interest (i.e. internationalization approaches, SCF and logistics capabilities) (see figure 2).

We identified five relational functions to manage SMEs internationalization processes (i.e. market management, knowledge management, network manage-

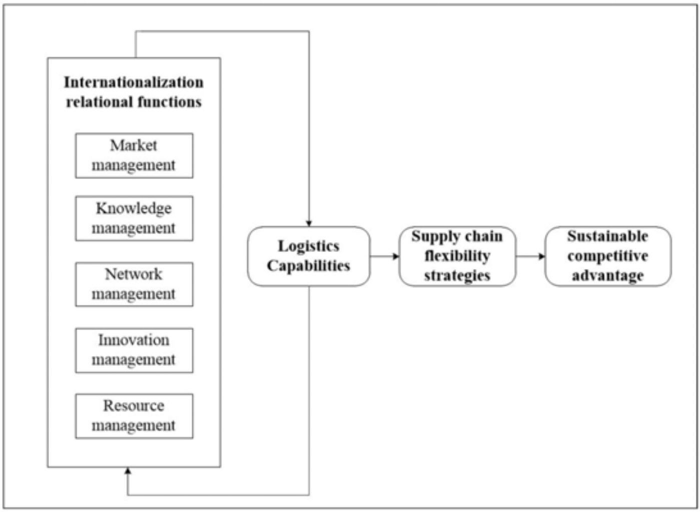

Figure 2: Conceptualizing SMEs internationalization, logistics capabilities and SCF relationship

ment, innovation management and resource management). These functional areas will enable the integration of information, resources, processes, operations, and capabilities with the SMEs-supply-chain partners. In the other hand, the development of logistics capabilities will enable the alignment of the firm with the customer demand as well as the supply side. The result of this iteration will contribute to the achievement of SCF strategies and as a consequence to the development of a sustainable competitive advantage. Further hypothesis and empirical research are needed to support the conceptualized relationships.

Additionally to the contribution to the theory regarding the role of the logistics capabilities in achieving SCF strategies for SMEs internationalization, there are also managerial implications. Managers and decision makers need to recognize the necessity of developing logistics capabilities in order to create sustainable internationalization strategies. SMEs might shift and respond more effectively to the dynamics of international markets by increasing their interior and exterior flexibility, alignment, and integration. Moreover, this will lead to improving SMEs innovation and logistics management due to the positive influence of logistics capabilities and SCF on creating value and better managing limited resources.

References

Bilkey, W. J. and G. Tesar (1977). “The Export Behavior of Smaller-Sized Wisconsin Manufacturing Firms”. In: *Journal of International Business Studies* 8.1, pp. 93–98.

Cavusgil, S. T. (1980). “On the internationalization process of firms.” In: *European research* 8.6, pp. 273–281.

Cavusgil, S. T. (1984). “Differences Among Exporting Firms Based on Their Degree of Internationalization”. In: *Journal of Business Research* 12.2, pp. 195–208.

Christopher, M. (2000). “The agile supply chain: competing in volatile markets”. In: *Industrial marketing management* 29.1, pp. 37–44.

Duclos, L. K., R. J. Vokurka, and R. R. Lummus (2003). “A conceptual model of supply chain flexibility”. In: *Industrial Management & Data Systems* 103.6, pp. 446–456.

Esper, T. L., B. S. Fugate, and B. Davis-Sramek (2007). “Logistics Learning Capability: Sustaining the Competitive Advantage Gained Through Logistics Leverage”. In: *Journal of Business Logistics* 28.2, pp. 57–82.

Felzensztein, C., L. Ciravegna, P. Robson, and J. E. Amorós (2015). “Networks, Entrepreneurial Orientation, and Internationalization Scope: Evidence from Chilean Small and Medium Enterprises”. In: *Journal of Small Business Management* 53, pp. 145–160.

Freiling, J. and C. L. Schelhowe (2014). “The Impact of Entrepreneurial Orientation on the Performance of Internationalization”. In: *Journal of Entrepreneurship, Management and Innovation* 10.4, pp. 169–199.

Gelinas, R. and Y. Bigras (2004). “The Characteristics and Features of SMEs: Favorable or Unfavorable to Logistics Integration?” In: *Journal of Small Business Management* 42.3, pp. 263–278.

Gligor, D. M. (2014). “The role of demand management in achieving supply chain ag ility”. In: *Supply Chain Management: An International Journal* 19.5/6, pp. 577–591.

Gligor, D. M. and M. C. Holcomb (2012). “Understanding the role of logistics capabilities in achieving supply chain agility: a systematic literature review”. In: *Supply Chain Management: An International Journal* 17.4, pp. 438–453.

Gosling, J., L. Purvis, and M. M. Naim (2010). “Supply chain flexibility as a determinant of supplier selection”. In: *International Journal of Production Economics* 128.1, pp. 11–21.

Hock Soon, Q. and Z. Mohamed Udin (2011). “Supply chain management from the perspective of value chain flexibility: an exploratory study”. In: *Journal of Manufacturing Technology Management* 22.4, pp. 506–526.

Ismail, H. S., J. Poolton, and H. Sharifi (2011). “The role of agile strategic capabilities in achieving resilience in manufacturing-based small companies”. In: *International Journal of Production Research* 49.18, pp. 5469–5487.

Johanson, J. and J.-E. Vahlne (1977). “The Internationalization Process of a Firm - a Model of Knowledge Foreign and Increasing Market Commitments”. In: *Journal of International Business Studies* 8.23, pp. 23–32.

Johanson, J. and J.-E. Vahlne (2009). “The Uppsala internationalization process model revisited: From liability of foreignness to liability of outsidership”. In: *Journal of International Business Studies* 40.9, pp. 1411–1431.

Johanson, J. and J.-E. Vahlne (1990). “The Mechanisms of Internationalization”. In: *International Marketing Review* 7.4, pp. 11–24.

Koste, L. L. and M. K. Malhotra (1999). “A theoretical framework for analyzing the dimensions of manufacturing flexibility”. In: *Journal of operations management* 18, pp. 75–93.

Kumar, P., R. Shankar, and S. S. Yadav (2008). “Flexibility in global supply chain: modeling the enablers”. In: *Journal of Modelling in Management* 3.3, pp. 277–297.

Kumar, V., K. A. Fantazy, U. Kumar, and T. A. Boyle (2006). “Implementation and management framework for supply chain flexibility”. In: *Journal of Enterprise Information Management* 19.3, pp. 303–319.

Lee, H. L. (2004). “The triple-A supply chain”. In: *Harvard Business Review* 82.10, pp. 102–120.

Leonidou, L. C. (2004). “An Analysis of the Barriers Hindering Small Business Export Development”. In: *Journal of Small Business Management* 42.3, pp. 279–303.

Lummus, R. R., L. K. Duclos, and R. J. Vokurka (2003). “Supply chain flexibility: building a new model”. In: *Global Journal of Flexible Systems Management* 4.4, pp. 1–13.

Mandal, S. (2016). “Towards an Integrated Logistics Capabilities Model of Supply Chain Flexibility: a Social Exchange Perspective”. In: *Romanian Economic and Business Review* 11.3, pp. 44–67.

Martínez Sánchez, A. and M. Pérez Pérez (2005). “Supply chain flexibility and firm performance: A conceptual model and empirical study in the automotive industry”. In: *International Journal of Operations & Production Management* 25.7, pp. 681–700.

McDougall, P. P. and B. M. Oviatt (2000). “International entrepreneurship: The intersection of two research paths”. In: *Academy of management Journal* 43.5, pp. 902–906.

Mellat-Parast, M. and J. E. Spillan (2014). “Logistics and supply chain process integration as a source of competitive advantage”. In: *The International Journal of Logistics Management* 25.2, pp. 289–314.

Mentzer, J. T., J. S. Keebler, N. W. Nix, C. D. Smith, and Z. G. Zacharia (2001). “Defining Supply Chain Management”. In: *Journal of Business Logistics* 22.2, pp. 1–25.
Mentzer, J. T., M. Soonhong, and L. M. Bobbitt (2004). “Toward a unified theory of logistics”. In: *International Journal of Physical Distribution & Logistics Management* 34.8, pp. 606–627.
Morash, E. A., C. L. M. Droge, and S. K. Vickery (1996). “Strategic logistics capabilities for competitive advantage and firm success”. In: *Journal of Business Logistics* 17.1, pp. 1–22.
Oviatt, B. M. and P. P. McDougall (2005). “Defining international entrepreneurship and modeling the speed of internationalization”. In: *Entrepreneurship: Theory and Practice* 29.5, pp. 537–553.
Pihkala, T., E. Varamaki, and J. Vesalainen (1999). “Virtual organization and the SMEs: a review and model development”. In: *Entrepreneurship & Regional Development* 11.4, pp. 335–349.
Sethi, A. K. and S. P. Sethi (1990). “Flexibility in manufacturing: A survey”. In: *International Journal of Flexible Manufacturing Systems* 2.4, pp. 289–328.
Singh, R. K., S. K. Garg, and S. Deshmukh (2008). “Strategy development by SMEs for competitiveness: a review”. In: *Benchmarking: An International Journal* 15.5, pp. 525–547.
Singh, R. K. and P. Acharya (2013). “Supply chain flexibility: A frame work of research dimensions”. In: *Global Journal of Flexible Systems Management* 14.3, pp. 157–166.
Slack, N. (1983). “Flexibility as a manufacturing objective”. In: *International Journal of Operations & Production Management* 3.3, pp. 4–13.
Stank, T. P., B. R. Davis, and B. S. Fugate (2005). “A Strategic Framework for Supply Chain Oriented Logistics”. In: *Journal of Business Logistics* 26.2, pp. 27–46.
Stevenson, M. and M. Spring (2007). “Flexibility from a supply chain perspective: definition and review”. In: *International Journal of Operations & Production Management* 27.7, pp. 685–713.
Tiwari, A. K., A. Tiwari, and C. Samuel (2015). “Supply chain flexibility: a comprehensive review”. In: *International Journal of Retail & Distribution Mangement* 38.7, pp. 767–792.
Upton, D. M. (1994). “The Management of Manufacturing Flexibility”. In: *California Management Review* 36.2, pp. 72–89.
Verdú-Jover, A. J., F. J. Lloréns-Montes, and V. J. García-Morales (2006). “Environment – Flexibility Coalignment and Performance : An Analysis in Large versus Small Firms”. In: *Journal of Small Business Management* 44.3, pp. 334–349.
Zhang, X., X. Ma, Y. Wang, and Y. Wang (2014). “How can emerging market small and medium-sized enterprises maximise internationalisation benefits? The moderating effect of organisational flexibility”. In: *International Small Business Journal* 32.6, pp. 667–692.

Part II

Advanced Manufacturing and Industry 4.0

Data Mining and Fault Tolerance in Warehousing

Christopher Reining[1], Omar Bousbiba[1], Svenja Jungen[1], Michael ten Hompel[1]

1 – TU Dortmund University

This paper surveys the significance of data mining techniques and fault tolerance in future materials flow systems with a focus on planning and decision-making. The fundamental connection between data mining, fault tolerance, and materials flow is illustrated. Contemporary developments in warehousing are assessed to formulate upcoming challenges. In particular, the transition towards distributed systems and the increasing data volume is examined. The significance of taking fault tolerance into account is emphasized. Ultimately, research issues are derived by conflating the previous findings. They comprise a holistic approach towards the integration of data science and fault tolerance techniques into future materials flow systems. Tackling these research issues will help to proactively harmonize the data representation to specific data mining techniques and increase the reliability of such systems.

Keywords: Materials Flow System; Data Mining; Fault Tolerance; Survey

1 Introduction

1.1 Increasing Data Volume and Data-Driven Operations

Nowadays the amount of available data in materials flow systems grows faster than the performance of computers to process them. Due to the implementation of superior sensors, more data is available for analysis. The application of distributed systems and current trends such as Internet of Things (IoT), Cyber-physical systems (CPS) and Industry 4.0 reinforce this trend (Xu, He and Li, 2014; International Controller Association, 2014; Hofmann and Rüsch, 2017). Smart devices are expected to decide and act autonomously or in collaboration with each other (Schuh and Stich, 2014, pp.203–213). Decentralization is seen as necessary in order to increase flexibility, reduce reaction time, and adapt to unplanned scenarios (Wilke, 2008). Accordingly, the area of decision-making broadens, input factors diversify, and standardized processes are fragmented or eliminated. Then again, there is a desire for predetermination when it comes to planning and controlling materials flow systems. Paradoxically, further information gathering and processing do not necessarily facilitate decision-making (Günthner and Ten Hompel, 2010, pp.2–5). Emerging data analysis methods are expected to create valuable information for both humans and machines to enable enhanced cooperation (Klötzer and Pflaum, 2015). Superior data processing shall relieve human workers by taking on recurring decisions autonomously.

In contrast to other scientific fields, there is little knowledge about data analytics in logistics so that further research is crucial (Rahman, Desa and Wibowo, 2011). Firms consider data and its analysis as a relevant resource to ensure their future competitiveness (Mazzei and Noble, 2017). At the current stage, data in warehousing systems is mainly used for anomaly detection and process control. To achieve additional benefit from the potential offered by the available data, processing methods for proactive optimization and prediction have to be enabled. Data-driven operations require relevant information to be obtained from raw data (Manyika et al., 2015). Their implementation connects human employees and their creativity in solving problems with state-of-the-art technology so that both can act ideally in real-time. This results in an environment which actively supports the cooperation of man and technology. The transition from warehousing as an isolated task into digital social networks is proposed by “Social Networked Industry” (ten Hompel, Putz and Nettsträter, 2017).

1.2 Rising communication complexity

From the findings of the previous subsection it can be concluded that distributed systems will be more widely used in future logistics facilities. In such systems, tasks are spread and solved in smaller groups of autonomous cooperating computing systems (Becker, Weimer and Pannek, 2015), that are also referred to as nodes. A distributed system can be described as a collective set of nodes, which interact with each other through message exchange. In contrast to centralized systems, there is no so-called "master-node", which holds the full control over all components in the system (Tanenbaum and Steen, 2008). Moreover, the application of a distributed system is often predetermined by the physical distribution of its components.

Each node has to be able to cooperate with each other node, e.g. by exchanging messages. All tasks have to be distributed and processed by each participating node in the distributed system. If several individual tasks exhibit time causal dependency or are limited due to physical restrictions, nodes have to be able to coordinate their tasks with each other. Two autonomous intelligent forklift trucks that try to take goods from a narrow alleyway are an exemplary case. If they are unable to coordinate, a deadlock might occur. A deadlock describes a blocking state of a system in which each participating node N_i blocks each other node N_j ($i \neq j$) by holding a lock on a particular object O_i (object O_i is locked by node N_i) of interest. Suppose that a group of cooperating autonomous forklift trucks tries to gather goods from a narrow alleyway. Further suppose that one of the forklift trucks crashes. As long as the fault is not detected, all forklift trucks may remain in a blocking state.

The coordination problem can be simplified when all fault-free nodes of a distributed system share the same global view of open tasks as well as a global view of the progress of accomplished tasks. Depending on their malfunction, faulty components can hinder the fault-free nodes from reaching a global view.

Due to the complexity of future distributed systems and the increasing reliability requirement (e.g., autonomous cooperating forklift trucks working in the same area as a human worker), it is important to make these systems resilient against faults. Otherwise, corruption (e.g., flash corruption due to supply voltage faults) of subcomponents will result in high costs and/or safety risks. This may cause the distributed system to enter an unsafe state. The problem of ensuring that fault-free nodes of a distributed system always share the same global view (reaching an agreement or consensus) independent of any presence of faulty nodes is also known as Byzantine agreement problem. The Byzantine generals' problem was first introduced by Lamport, Shostak and Pease (1982). With the help of agreement protocols, reaching a global view among fault-free nodes becomes possible. Byzantine agreement protocols have a long tradition. Thus, the state-of-the-art in the design of agreement protocols compromised a huge number of solutions (Lamport, Shostak and Pease, 1982; Jochim and Forest, 2010). Therefore, the fundamental problem of reaching agreement in the presence of faulty components can be seen as solved. Its unsolvability for different fault assumptions and/or system models has been proven by both Fischer, Lynch and Paterson (1985) and Santoro and Widmayer (2007).

Now, the challenge has become an optimization problem of the communication complexity (e.g., reducing the total number of communication rounds, number of redundant nodes and message transmission per communication round) which depends on the number of tolerated faults (Jochim and Forest, 2010; Khosravi and Kavian, 2012; Bousbiba, 2015).

1.3 Contribution and Outline

This paper contributes scientific hypotheses and questions to be evaluated in further projects in the field of materials flow systems, data mining and fault tolerance. It constitutes the necessary knowledge basis and sensitizes the ensuing issues from both an academic and an industrial point of view (BVL - Bundesvereinigung Logistik e. V., 2017).

The rest of the paper is organized as follows: The second section contemplates warehousing from a researcher's perspective. The link to knowledge discovery and the transition towards distributed systems are discussed. The third section further illustrates the significance of fault tolerance in this context. Finally, research issues are derived based on the previous findings.

2 Challenges in Materials Flow Systems

2.1 Warehousing Operations and Tasks

As shown in figure 1, warehousing employs three elements, namely systems, processes and management. Thus, a feasible way to formalize operations is to consider them as a combination of these elements. This approach implies a wide variety of configurations. In basic terms, warehousing processes are conducted within a system in accordance with an underlying management strategy. Typical planning and decision tasks interact with these operations. They comprise technology selection, capacity planning of personnel and equipment and packaging planning.

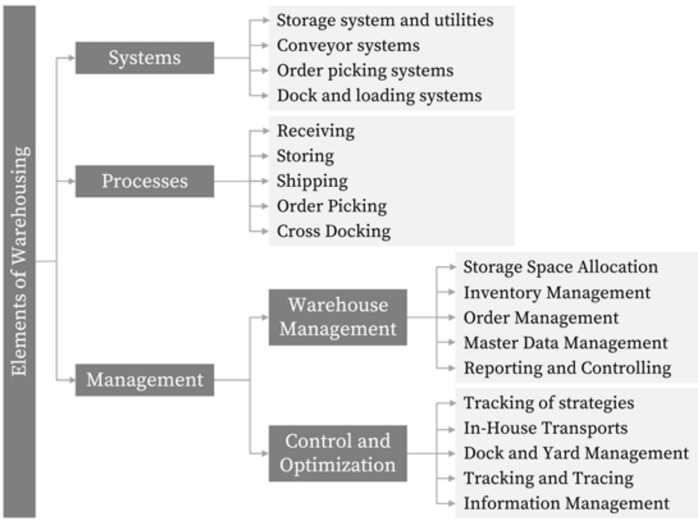

Figure 1: Elements of warehousing (Rohrhofer and Graf, 2013, pp.8–9)

As illustrated in figure 1, the storage space allocation of each article is defined by the warehouse management. It influences the effort of each order picking process, for example the travel time to corresponding storage locations. Likewise, the layout of the order picking system has a potentially major impact as it determines each shelf's position. More sophisticated warehousing principles cause more complex combinations of the elements. In a two-stage order picking system the interaction with the conveyor system would have to be taken into account. Then again, a conveyor itself is a electromechanical component. The aforementioned context emphasizes the interdependency of planning and decision tasks with warehousing. Other points of view, e.g. from maintenance or performance availability, reveal further ties.

On one hand, formalization of warehousing operations is desired in order to apply methods from other fields of science and represents a current research issue. On the other hand, task solving requires a high degree of domain knowledge. Running a warehouse is often characterized not only by interdependencies but uncertainties and rising task-complexity (Faber, de Koster and Smidts, 2013; Schieweck, Kern-Isberner and ten Hompel, 2016). These aspects hinder the application of analytical approaches. The required data, target figures and restrictions are depending on the operation's configuration and decisions already taken in related tasks.

Analytical approaches can be found in a wide range of technical standards and scientific works. They are limited to specific subsystems and use cases because warehousing is characterized by parallel and sequential operations that rigid formulas can hardly deal with. Materials flow simulation offers an alternative to deal with this issue. The commonly used discrete event simulation yet requires formalized operations and input parameters to obtain useful information (Timm and Lorig, 2015). Once the observed (sub-)system exceeds a certain level of complexity both analytical and simulative approaches tend to be infeasible to use in practical application (Roessler, Riemer and Mueller, 2015). They are either based on heavily simplified assumptions or they require a disproportional effort, e.g. specialized personnel or long preparation and running time of the simulation models (Frank, Laroque and Uhlig, 2013).

Applicable methods of data collection rely on observation and posterior analysis. In most cases, the conventional method of turning raw data into useful knowledge is done by manual analysis and interpretation (Bohács, Gáspár and Rinkács, 2012). Due to the necessary domain knowledge and insufficient formalization, the analysis and information extraction is conducted by specialists. While planning tasks usually offer a relatively long time frame, many decisions concerning warehousing are of short-term nature. For example, newly incoming goods in a distribution centre have to be assigned to one of several possible storage locations without a time lag. The assignment to a location is then performed based on a multitude of input factors of which some, e.g. the daily retrieval volume for the upcoming weeks, may not be available yet. Nevertheless, these figures may be predictable from past data. In such cases, warehousing operations can be expected to improve once they are data-driven.

2.2 Application of Knowledge Discovery and Data Mining

It is estimated that about 60% of data mining projects fail (Goasduff, 2015). Concerning warehousing, potential issues leading to this unsatisfactory situation are outlined.

The figure 2 below illustrates a widely recognized approach towards Knowledge Discovery in Databases (KDD) as proposed by Fayyad, Piatetsky-Shapir and Smyth (1996). Its nine steps are considered more closely to assess the applicability of the KDD process in warehousing. An overview of alternative process models is provided by Mariscal, Marbán and Fernández (2010). In literature, there is a wide variety of coexisting terminologies for data science related terms. Still, the drawn conclusions are valid regardless of the used terminology. A potential distinction of related terms is provided by Mitchell-Guthrie (2014).

The first step in the process is to develop an understanding of the observed system, gather necessary domain knowledge and identify the goal of the KDD process. While the warehouse operators may provide the necessary domain knowledge, goals can be derived from different sources. In warehousing there is a wide variety of key figures to examine. The goals may be set by technical staff or stipulated by the senior management.

Next, a target data set has to be created. For example, data about the past throughput volume or technical properties of the stored goods and their assignment to a storage location may be of interest. This data can be taken from the Warehouse Management System (WMS), Enterprise Resource Planning System (ERP) or other sources of information. Most IT-systems in use have evolved historically without regards to Knowledge Discovery. Human practitioners often generate article master data with emphasis on easy comprehensibility. Redundancy or noise

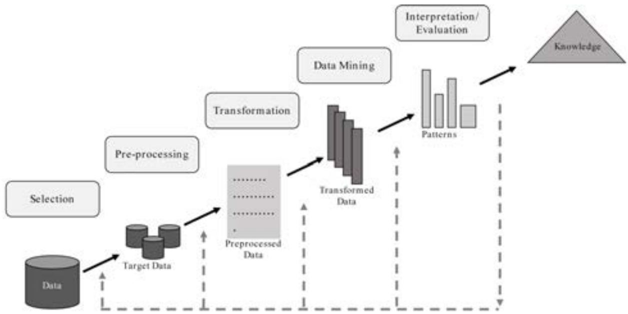

Figure 2: Overview of the KDD Process according to Fayyad, Pi-atetsky-Shapir and Smyth (1996)

avoidance has usually not been the priority when implementing the information systems.

The third step comprises data cleansing and pre-processing. This is necessary because the gathered data will very likely have inconsistencies, errors, out of range values, missing values and so forth. The goal of this step is to bring the data into a state which enables data mining methods to work as intended. While being time-consuming and labour-intensive, pre-processing facilitates the proceeding steps (Witten et al., 2017, pp.56–65). The same is true for the fourth step, data transformation. It comprises the search for useful features to represent the distinctive characteristics of the data. This procedure often goes along with dimensionality reduction. Data cleansing, pre-processing and transformation have to be conducted in accordance with the requirements of each data mining method. Accordingly, previous steps have to be repeated iteratively once an operation or an outcome turns out to be infeasible later on. The often given short-term nature of warehousing operations suggests that the utilization of data mining is vitally dependent on an efficient data preparation. An overview of pre-processing methods is provided by García, Luengo and Herrera (2016).

Data mining itself appears as the fifth step of the KDD process. A particular data mining method has to be matched with the predefined goal of the KDD process. The sixth step comprises the selection of a hypothesis and a data mining algorithm. The search for useful patterns and interesting information is conducted in the seventh step. It is crucial to recognize helpful data mining methods and algorithms for each warehousing task to exploit their potential. The chosen method and algorithm codetermine the optimal configuration of the overall KDD process. There are two thinkable scenarios but not limited to the following. Either the sheer amount of data is too big to be manually analysed, impeding data-driven decisions or the necessary information for making a valid decision is unknown beforehand.

While the first scenario is a topic of descriptive data mining, the second is a conceivable scenario of predictive data mining. Both scenarios may coincide in practice.

A common way to differentiate data mining methods is given by Fayyad, Piatetsky-Shapir and Smyth (1996):

- Regression
- Anomaly detection
- Association rule learning
- Clustering
- Classification
- Summarization

The data mining algorithm defines the model representation, the evaluation and the search method. For example, concrete algorithms of the regression method are, among others, the linear, polynomial and logistical regression. It is obvious that practitioners that choose to implement data mining methods are required to observe a multitude of possibilities. The question arises, which of the available methods and algorithms correspond to one or more warehousing tasks.

In the eight step the mined patterns are interpreted, e.g. by visualization. Previous steps may be repeated in further iterations of the KDD process. This is the case when the knowledge gain and its usability turn out to be insufficient. Often occurring short-term nature of warehousing operations suggests that time-consuming iterations are disadvantageous. They are ought to be avoided by a reasonable configuration of the KDD process in the first place. In the final step, the extracted knowledge is validated and made available for further processes.

To conclude this section, existing approaches to integrate KDD and data mining in warehousing are referenced. Ming-Huang Chiang, Lin and Chen (2014) presented an approach to improve the efficiency of order picking systems by finding associations between orders. The associations are the basis for heuristics to minimize the travel distance. Pang and Chan (2017) utilized data mining to find relationships among costumer orders. The identification of relationships helps to determine rational storage locations to minimize the picking effort. Gils et al. (2016) introduced an approach to predict the workload of order picking zones based on past data. The forecast can be used to determine the required number of employees and their assignment within the warehouse in a rational manner. Knoll, Prüglmeier and Reinhart (2016) presented an approach to use machine learning for predictive inbound logistics planning. It facilitates the system's adaptation to future scenarios. Their approach is based on the development of a logistics information structure (ontology).

The literature review shows that so far there is little effort spent on embedding data mining methods and algorithms into a holistic KDD process. They rather focus on finding suitable methods and algorithms for specific problems.

2.3 Distributed Systems in Warehousing

A central unit (master-node) controls the majority of current materials flow components. For example, a high-bay storage, a sorting system or a pick-by-light system are self-contained units in the sense that all information gathered and all decisions made within this system refer to a central unit. Therefore, warehousing operations are not triggered and conducted along several units. They are coordinated with help of the ERP, WMS or other central IT systems instead. To face the increasing flexibility demand, the distribution of warehousing operations among autonomous units is a current topic in both academic and industrial research. The underlying idea of realisation approaches is a plug-and-play behaviour of autonomous agents also referred to as ad-hoc-networking. Each agent is a modular unit (Lieberoth-Leden, Regulin and Günthner, 2016; Seibold and Furmans, 2017). In a distributed system, the warehousing system components are fluctuating. For example, the layout of the order picking zones cannot be assumed static once the facility is built. The system is repeatedly shifting its form in short terms. Agents may enter or leave the system for a multitude of reasons such as the required performance capacity, maintenance intervals and so forth. Furthermore, a single benign malfunctioning agent (e.g. fail-silent or crash) does not necessarily lead to a system crash, as it would be the case with a malfunctioning conveyor system in a high bay storage. Exemplary realisation approaches are referenced below.

Karis Pro (Colling et al., 2016) is an automated guided vehicle. Decentralized job creation without a prior teaching of transport connections between transfer points offers flexibility towards layout changes. Due to its modular construction and decentralized control, additional hardware like a central master computer are not necessary. Toru Robot (Kremen, 2016) is a warehouse robot that is able to pick items off shelves autonomously. In order to identify objects the robots create a map using laser sensors that scan the environment. This data is shared with other robots working in the same warehouse. The Grid Sorter (Colling, Seibold and Furmans, 2016) is a conveyor system which provides efficient and space-saving sorting of goods. The system's decentralized controllers and its structure consisting of identical rectangular conveyor modules allow flexible adaption to changing requirements. A reservation algorithm facilitates the transportation of goods, which are larger than a single conveyor module. The use of Cellular Transport Vehicles (Kirks et al., 2012) offers possibilities for areas where flexibility and changeability is required, planning reliability is not guaranteed or automation is not desired due to the lack of flexibility. The communication and control among the entities is realized by a decentral architecture. They are flexible in their topology meaning the formation of the entities is changeable at any time. Research and applications of distributed materials flow systems are neither geographically restrained to Europe (GreyOrange, 2017) nor solely focused on packaged goods (Serva Transport Systems, 2017). A further overview is given by Karabegović (2015).

The literature review shows that current research on distributed materials flow systems mainly focuses on technical issues regarding control and organization of the agents such as deadlock prevention or safety aspects (see e.g. (Kopecki, 2015)). So far, the data collection and processing, e.g. by the agent's environmental sensors, are subordinate to this purpose. Therefore, the data representation among agents from different suppliers is very likely not harmonized. As each agent is a source of data, the number and heterogeneity of data sources increases. Consequently, manual data analysis becomes increasingly impractical. The findings in this subsection further emphasize the urgency of proactively integrating knowledge discovery methods in future materials flow systems.

3 Fault Tolerance

The information in future distributed materials flow systems will be gathered from different locations and mobile systems. Using a centralized approach of data collection will be slow and expensive because all transferred information must be gathered by the master node. In other words, the entities and the master node need to be fully connected. Due to the communication bottleneck, costs and high communication overhead, it can be concluded that a distributed solution (i.e. a distributed knowledge discovery system) will be applied.

Data mining techniques in a distributed knowledge discovery system may help to improve the overall system by providing useful information to the group. This information (e.g., on several blocking areas) can be used by the autonomous robots to adapt their path planning in real-time in order to meet their constraints. Thus, the group will not reach a temporary deadlock.

In a distributed system, a global view has to persevered even if some of the components behave faulty. Otherwise, the extracted knowledge from the gathered datasets may result in faulty decisions. Another important aspect is the time in which a decision has to be made. Cooperating agents may rely on the knowledge extracted by the distributed knowledge discovery system in real time. This implies that the decision made by a distributed knowledge discovery system has a big impact on the effectiveness and efficiency of the overall logistics system (Dou, Chen and Yang, 2015).

Although the information provided by data mining can help to improve the effectiveness and efficiency of the overall logistics system, fault tolerance techniques must be applied nevertheless. The efficiency of large and/or complex distributed system heavily depends on the correct behaviour of its components and the decision made with the help of a distributed knowledge discovery system. For instance, Lee and Lin (2006) have shown that data mining techniques combined with fault tolerance techniques are able to cope with a certain degree of polluted data (containing a certain degree of noise, which – without using fault tolerance techniques – would lead to ambiguous conclusions).

4 Identification of Research Issues

In section 2.2 it has been stated that an efficient design and quick application of the KDD process require the data mining method and algorithm to be determined beforehand. Consequently, it is necessary to define a framework which allows the assignment of data mining methods and algorithms on one side to warehousing tasks and the given time horizon on the other side. An approach to this issue is given in figure 3. While data science provides methods and algorithms, warehousing tasks need to be formalized and abstracted to be assigned to them. The time horizon possibly restricts feasible methods. As illustrated in figure 3, the long-term packaging planning (e.g., the necessary amount of pallets or packages in a specific time frame) is a possible use case of regression. In contrast, storage space allocation as a short-term decision could be a use case for classification. In such a case, formalization becomes an issue. The classification of articles is not static over time. The retrospectively identified best classification is not necessarily the actually applied classification at the time the goods had been examined for the first time. This discrepancy is usually not shown in the provided data. A high degree of domain knowledge is necessary to retrospectively identify the best classification of an article.

The overview is far from being complete and serves as a starting point for further research. An identified match of a warehousing task and a data mining method does not necessarily mean that data science provides the best solution. Analytical or simulative approaches may provide better solutions in regards to accuracy and/or expenditure of time. Determining the limits of these approaches may reveal a variety of feasible use cases of data mining in warehousing for further examination.

In distributed systems, the harmonization of data representation among the agent becomes an issue. A standardized framework can take the requirements of efficient data mining into account. An industrial standard to be used by all suppliers of materials flow components may be the final goal of this approach.

The question arises in what way the necessary computing capacity for short-term data mining applications is provided. The data could be gathered and processed by a central unit, by each agent on its own (with sufficient computing capacity) or cooperative by a multitude of agents (distributed). As stated in Section 3 any form of cooperation requires a certain degree of fault tolerance, such as in a distributed knowledge discovery system and/or cooperative multi-agent system.

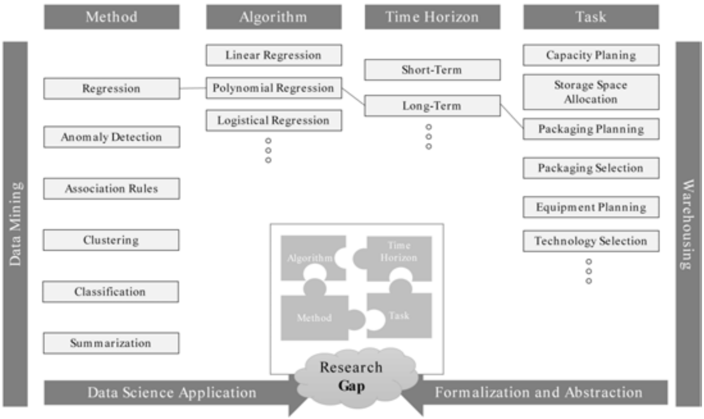

Figure 3: Research Gap between data mining methods and warehousing tasks

With respect to fault tolerant solutions in future distributed materials flow systems, the following research issues were identified. Designing an efficient Byzantine agreement protocol for different network topologies (Tanenbaum and Steen, 2008) is required as the complexity of materials flow systems will grow. In general, agreement protocols require a quadratic communication overhead to solve the Byzantine agreement problem. By relaxing the fault assumption (Jochim and Forest, 2010; Khosravi and Kavian, 2012) to simple faults (e.g., which cause fail silent behaviour) it is possible to solve the problem with linear communication overhead. However, such solutions cannot be applied in the presence of malicious faults (e.g., benign or malicious Byzantine faults).

One way to reduce the communication overhead is to design or deploy new efficient fault tolerant signature algorithms (Echtle, 1999). Many agreement protocols suffer from redundant message transmissions (Jochim and Forest, 2010). To provide fault tolerance, messages need to be retransmitted in recurrent communication rounds. It raises the question whether the design of a new signature algorithm may help to reduce the number of unnecessary retransmissions while simultaneously providing sufficient fault protection.

With the help of fault diagnosis algorithms and gossip-based membership protocols (Aljeri, Almulla and Boukerche, 2013) faults can be detected. Appropriate measures will be taken faster. As the detection of faulty behaviours without human interventions will play an important role in future logistics processes, such algorithms will help groups of cooperating nodes to remain functional in the presence of faults or breakdowns. For instance, if an intelligent forklift truck, which has reserved an area in order to complete its task, breaks down unexpectedly, it will block an area for a non-specific time. However, if the fault is detected by the other intelligent forklift trucks in the group, the area can be freed and the information about the faulty intelligent forklift truck can be further distributed to a sink, e.g. to a service engineer as well as to the knowledge discovery system.

5 Conclusion

The datasets being processed and analysed in future industry 4.0 warehousing applications will be tremendous. In order to extract useful knowledge from the gathered raw data, fault tolerant distributed knowledge discovery systems need to be applied. While there is a consensus that data science methods offer a great potential for planning and decision-making in warehousing, there is little knowledge about feasible use cases for data mining methods among typical warehousing tasks. This paper reviewed the status quo of data mining and fault tolerance. Crucial research issues have been derived and concrete approaches to address them have been outlined. In the Innovationslabor Hybride Dienstleistung, the Chair of Materials Handling and Warehousing at the TU Dortmund University plans to further work on this topic.

Acknowledgements

Parts of the work on this publication have been supported by Deutsche Forschungsgemeinschaft (DFG) in the context of the research project ”Human Activity Recognition in the Commissioning Process”.

References

Aljeri, N., M. Almulla, and A. Boukerche (2013). “An efficient fault detection and diagnosis protocol for vehicular networks”. en. In: ACM Press, pp. 23–30.

Becker, T., D. Weimer, and J. Pannek (2015). “Network structures and decentralized control in logistics: topology, interfaces, and dynamics”. In: *International Journal of Advanced Logistics* 4.1, pp. 1–8.

Bohács, Gáspár, and Rinkács (2012). “Adaptive simulation techniques for modeling material flow systems”. In: *2012 IEEE 10th Jubilee International Symposium on Intelligent Systems and Informatics*, pp. 559–564.

Bousbiba, O. (2015). “Reducing the Communication Complexity of Agreement Protocols By Applying A New Signature Scheme called SIGSEAM”. In: *DEPEND 2015 : The Eigth International Conference on Dependability*, pp. 29–32.

Bundesvereinigung Logistik e. V. (BVL) (2017). *Digitalisierung in der Logistik - Antworten auf Fragen aus der Unternehmenspraxis*.

Colling, D., S. Ibrahimpasic, A. Trenkle, and K. Furmans (2016). “Dezentrale Auftragserzeugung und -vergabe für FTF”. In: *Logistics Journal : Proceedings* 2016.10.

Colling, D., Z. Seibold, and K. Furmans (2016). “GridSorter – Dezentral gesteuertes Materialflusssystem zum Transport unterschiedlich großer Ladungsträger”. In: *Logistics Journal : Proceedings* 2016.05.

Dou, J., C. Chen, and P. Yang (2015). “Genetic Scheduling and Reinforcement Learning in Multirobot Systems for Intelligent Warehouses”. en. In: *Mathematical Problems in Engineering* 2015, e597956.

Echtle, K. (1999). “Avoiding Malicious Byzantine Faults by a New Signature Generation Technique”. In: *Dependable Computing ? EDCC-3*. Ed. by G. Goos, J. Hartmanis, J. van Leeuwen, J. Hlavi?ka, E. Maehle, and A. Pataricza. Vol. 1667. DOI: 10.1007/3-540-48254-7_9. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 106–123.

Faber, de Koster, and Smidts (2013). “Organizing warehouse management”. In: *International Journal of Operations & Production Management* 33.9, pp. 1230–1256.

Fayyad, U., G. Piatetsky-Shapir, and P. Smyth (1996). “From Data Mining to Knowledge Discovery in Databases”. In: AI Magazine, pp. 37–54.

Fischer, M. J., N. A. Lynch, and M. S. Paterson (1985). “Impossibility of Distributed Consensus with One Faulty Process”. In: *J. ACM* 32.2, pp. 374–382.

Frank, M., C. Laroque, and T. Uhlig (2013). “Reducing computation time in simulation-based optimization of manufacturing systems”. In: IEEE, pp. 2710–2721.

García, S., J. Luengo, and F. Herrera (2016). “Tutorial on practical tips of the most influential data preprocessing algorithms in data mining”. In: *Knowledge-Based Systems* 98, pp. 1–29.

Gils, T. v., K. Ramaekers, A. Caris, and M. Cools (2016). “The use of time series forecasting in zone order picking systems to predict order pickers’ workload”. In: *International Journal of Production Research* 0.0, pp. 1–14.

Goasduff, L. (2015). *Gartner Says Business Intelligence and Analytics Leaders Must Focus on Mindsets and Culture to Kick Start Advanced Analytics*.

GreyOrange (2017). *GreyOrange Butler*.

Günthner, W. A. and M. ten Hompel (2010). *Internet der Dinge in der Intralogistik*. ger. VDI-Buch. OCLC: 845595346. Berlin: Springer.

Hofmann, E. and M. Rüsch (2017). "Industry 4.0 and the current status as well as future prospects on logistics". In: *Computers in Industry* 89, pp. 23–34.

Hompel, M. ten, M. Putz, and A. Nettsträter (2017). *Social Networked Industry*. Whitepaper. Fraunhofer IML, p. 10.

International Controller Association (2014). "Dream Car of the "Ideenwerkstatt" at the ICV 2014". In: pp. 1–59.

Jochim and Forest (2010). "An Efficient Implementation of the SM Agreement Protocol for a Time Triggered Communication System". In: *SAE Convergence 2010*.

Karabegović, I., E. Karabegović, M. Mahmić, and E. Husak (2015). "The application of service robots for logistics in manufacturing processes". In: *Advances in Production Engineering & Management* 10.4, pp. 185–194.

Khosravi, A. and Y. S. Kavian (2012). "Reaching an agreement in a distributed environment in absence of omission faults". In: *2012 8th International Symposium on Communication Systems, Networks Digital Signal Processing (CSNDSP)*, pp. 1–4.

Kirks, T., J. Stenzel, A. Kamagaew, and M. ten Hompel (2012). "Zellulare Transportfahrzeuge für flexible und wandelbare Intralogistiksysteme". In: *Logistics Journal* 2012.01.

Klötzer, C. and A. Pflaum (2015). "Cyber-physical systems as the technical foundation for problem solutions in manufacturing, logistics and supply chain management". In: *2015 5th International Conference on the Internet of Things (IOT)*, pp. 12–19.

Knoll, D., M. Prüglmeier, and G. Reinhart (2016). "Predicting Future Inbound Logistics Processes Using Machine Learning". In: *Procedia CIRP*. The Sixth International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV2016) 52, pp. 145–150.

Kopecki, L. (2015). "An Approach for Deadlock Prevention in Decentralized Controlled Pre-storage Zones with Dynamic Behavior and Time Windows". In: *International Journal of Materials, Mechanics and Manufacturing* 4.3, pp. 208–212.

Kremen, R. (2016). *Watch this new warehouse robot pick individual items from shelves*.

Lamport, L., R. Shostak, and M. Pease (1982). "The Byzantine Generals Problem". In: *ACM Trans. Program. Lang. Syst.* 4.3, pp. 382–401.

Lee, G. and Y. t. Lin (2006). "A study on Proportional Fault-tolerant Data Mining". In: *2006 Innovations in Information Technology*, pp. 1–5.

Lieberoth-Leden, C., D. Regulin, and W. A. Günthner (2016). "Efficient Messaging through Cluster Coordinators in Decentralized Controlled Material Flow Systems". en. In: *MATEC Web of Conferences* 81, p. 06005.

Manyika, J., M. Chui, P. Bisson, J. Woetzel, R. Dobbs, J. Bughin, and D. Aharon (2015). *Unlocking the potential of the Internet of Things | McKinsey & Company*. Tech. rep.

Mariscal, G., Ó. Marbán, and C. Fernández (2010). "A survey of data mining and knowledge discovery process models and methodologies". In: *The Knowledge Engineering Review* 25.2, pp. 137–166.

Mazzei, M. J. and D. Noble (2017). "Big data dreams: A framework for corporate strategy". In: *Business Horizons*.

Ming-Huang Chiang, D., C.-P. Lin, and M.-C. Chen (2014). "Data mining based storage assignment heuristics for travel distance reduction". en. In: *Expert Systems* 31.1, pp. 81–90.

Mitchell-Guthrie, P. (2014). *Looking backwards, looking forwards: SAS, data mining, and machine learning*.

Pang, K.-W. and H.-L. Chan (2017). “Data mining-based algorithm for storage location assignment in a randomised warehouse”. en. In: *International Journal of Production Research* 55.14, pp. 4035–4052.

Rahman, F. A., M. I. Desa, and A. Wibowo (2011). “A review of KDD-data mining framework and its application in logistics and transportation”. In: *The 7th International Conference on Networked Computing and Advanced Information Management*, pp. 175–180.

Roessler, M. P., J. Riemer, and M. Mueller (2015). “Decision Support for Choosing an Appropriate Simulation Method for Dynamic Material Flow Analysis”. In: *Journal of Industrial and Intelligent Information* 3.4.

Rohrhofer, C. and H.-C. Graf (2013). *Weissbuch der Intralogistik und Logistiktechnologie: Systemüberblick, Implementierung, Optimierung*. ger. OCLC: 854726145. Aachen: Shaker.

Santoro, N. and P. Widmayer (2007). “Agreement in synchronous networks with ubiquitous faults”. In: *Theoretical Computer Science*. Structural Information and Communication Complexity (SIROCCO 2005) 384.2, pp. 232–249.

Schieweck, S., G. Kern-Isberner, and M. ten Hompel (2016). “Intralogistik als Anwendungsgebiet der Antwortmengenprogrammierung – Potenzialanalyse”. In: *Logistics Journal : Proceedings* 2016.05.

Schuh, G. and V. Stich (2014). *Enterprise-Integration: auf dem Weg zum kollaborativen Unternehmen*. ger. VDI-Buch. OCLC: 879580815. Berlin: Springer Vieweg.

Seibold, Z. and K. Furmans (2017). “Plug&Play-Fördertechnik in der Industrie 4.0”. de. In: *Handbuch Industrie 4.0 Bd.3*. Ed. by B. Vogel-Heuser, T. Bauernhansl, and M. t. Hompel. Springer Reference Technik. DOI: 10.1007/978-3-662-53251-5_2. Springer Berlin Heidelberg, pp. 3–20.

Serva Transport Systems (2017). *EVE - Effiecient Variable Ergonomic: The driverless transport system for intralogistics*.

Tanenbaum, A. S. and M. v. Steen (2008). *Verteilte Systeme: Prinzipien und Paradigmen*. ger. 2., aktualisierte Aufl. it-informatik. OCLC: 237201545. München: Pearson Studium.

Timm, I. J. and F. Lorig (2015). “Logistics 4.0 - A challenge for simulation”. In: *2015 Winter Simulation Conference (WSC)*, pp. 3118–3119.

Wilke, M. (2008). “Dezentral steuern, zentral kommunizieren - ein Steuerungskonzept für wandelbare Materialflussysteme”. In: *Logistics Journal : referierte Veröffentlichungen* 2008.April.

Witten, I. H., F. Eibe, M. A. Hall, and C. J. Pal (2017). *Data mining: practical machine learning tools and techniques*. Fourth Edition. Amsterdam: Elsevier.

Xu, L. D., W. He, and S. Li (2014). “Internet of Things in Industries: A Survey”. In: *IEEE Transactions on Industrial Informatics* 10.4, pp. 2233–2243.

Influence of Patterns and Data-Analytics on Production logistics

Benjamin Kormann[1], Susanne Altendorfer-Kaiser[2]

1 – Robert Bosch GmbH

2 – Montanuniversität Leoben

The flow of information is an essential part of Industry 4.0, as more reliable process data is available and subsequent hardware changes provide for processing power to enable large-scale data analysis. Due to the fact that most data analytics and big data frameworks presume that Data-Mining- and Data-Analytics-Activities are conducted in form of projects, this paper focuses on the integration of data analytics and data mining into operational processes and the resulting consequences of the organization. Therefore a framework to implement data analytics workflows in production logistics to improve decision-making and processes is presented. By integrating data analytics workflows in production logistics applying the presented framework, more resources can be devoted to proactively discover and counteract possible bottlenecks or constrictions instead of resorting to firefighting and taskforce-activities. The methodology to derive such framework consists of developing and implementing data analytics use-cases along the supply chain in production logistics according to current big-data and data-analytics frameworks in cooperation with a large automotive supplier and modifying current frameworks and approaches to fit the company's requirements.

Keywords: Knowledge Discovery in Databases; Data Analytics; Process model; Supply Chain Analytics

1 Introduction

Current initiatives and research approaches investigate in intelligent, autonomous and decentralized subsystems that should lead to more competitive production and logistics processes - often revered to as "Industry 4.0" or "Internet of Things". These initiatives are not only driven by new technologies and methods of technical integration, in this context the information element is an essential asset for successful business: every business process - either service or production processes - requires a fundamental perception of information management to implement scientific logistics approaches to achieve an optimized supply chain (Jamil, Soares and Pessoa, 2017). Thus, Altendorfer-Kaiser (2015) states "Therefore the effective and economical integration of information and decision-making bodies is relevant".

Data and information are currently omnipresent and this oversupply of data and information for the business environment obtains more disadvantages than potentials for a company. In this context Information logistics becomes a cornerstone for companies: The goal of information logistics is to deliver the right information, in the right format, at the right place at the right time for the right people at the right price. (Uckelmann, 2012) Therefore an efficient information supply management is essential. However, information does not exist without data. And this is even important for the production industry as here data, information and generated insight based on the generated information are a major cornerstone for successful business in order to manage production processes and the resulting supply chains. (Fosso Wamba S., Akter S., 2015; Gimenez Isasi, Morosini Frazzon and Uriona, 2015; Militaru, Pollifroni and Ioanid, 2015; Meudt, et al., 2016; Corte-Real, Oliveira and Ruivo, 2017; Zhang, et al., 2017b; Zhang, et al., 2017a) Therefore this paper deals with the importance of big data in terms of production logistics and how big-data and analytics principles can be integrated in business processes extending existing knowledge discovery process models and which potential benefits can be derived by applying said model to business situations in production logistics.

The remainder is structured as follows: Section 2 provides background material on production logistics, big data analytics, smart data analytics, supply chain analytics, information and knowledge discovery process models. Section 3 discusses a possible extension of existing Knowledge discovery process models to ensure a lasting integration of big data analytics into business processes in production logistics. Section 4 discusses current application of the proposed model in use-cases in the automotive supplier industry. Section 5 provides a summary and concluding remarks.

2 Background

2.1 Production logistics

Production logistics will be defined in this article as all operational purchasing, in-house material flow, in-house material handling, operational distribution and information flow processes which do need to be organized, controlled, executed and optimized in order to supply necessary raw-materials, perform manufacturing operations and physically distribute finished goods to customers. (Arnold, 2006; Günther and Tempelmeier, 2014; Wang, et al., 2016; Krieger W., 2017). Therefore, in order to facilitate further references to the mentioned process the SCOR-Model reference framework will be used to cluster the activities into Plan-, Source-, Make- and Deliver-Processes in Production Logistics (Bolstorff, Peter A., Rosenbaum, Robert G., Pohula, Rolf G., 2007; Supply-Chain Council, 2008) effectively defining production logistics as the management of in-house supply chains supplying manufacturing activities. In the context of Industry 4.0 many manufacturing related activities are being digitalized and products or manufacturing equipment are transformed in to cyber-physical systems which constantly gather data. (Schöning H., 2017) The resulting data can be considered Big Data, as the gathered data is being generated in near real-time. (Schöning H., 2017) In order to cope with such systems, pattern identification and other analytics tools related to Big Data serve as a viable way to handle complexity (Wehberg G., 2016) and in turn by actively handling complexity creating a basis which ensures future competitiveness and adaptability. (Schuh, Krumm and Amann, 2013; Leveling, Edelbrock and Otto, 2014)

2.2 Data and Information

In order to talk about information in general and for logistics in particular, it is important at this point to define the terms data and information to connect information and logistics in a more appropriate way. One approach can be seen in Figure 1.

Data: The noun data is defined as facts and statistics collected together for reference or analysis. The term itself comes from the Latin plural of "datum".

Today organizations generate large amounts of multi-spectral data. In view of its discrete form, data in itself may not be very useful, so it is often referred to as the original knowledge asset. When data is processed into a context, it becomes information. (Bali, Wickramasinghe and Lehaney, 2009)

Information: For this paper the relevant definition of information is defined as something that is conveyed or represented by a particular arrangement or sequence. The term information origins in the Latin verb "informare" (in English" to inform"), which means 'to give from' or 'to form an idea of'. Furthermore the Latin noun "informatio" had already had the meaning of concept and idea". (Bali, Wickramasinghe and Lehaney, 2009) mentioned that information is data that has been arranged into a meaningful pattern and thus has an identifiable shape. An example is a report created from intelligent database queries. (Bali, Wickramasinghe and Lehaney, 2009) also found that information and communication technology not only increase the communication abilities with data but also accelerate the transferring and processing of this data into information.

When talking about data and information it is also interesting to have look on IBMs "Business Information Maturity Model", which defines five levels of data management and is shown in figure 2.

The focus of data at the lowest level is from an operational perspective. At the next level, the Information is used to manage the company. The Information becomes a strategic asset at the next level. At the next level the Information becomes a form of special expertise. Finally, at the top level, the Information is what give the company a competitive advantage and therefore often needed to be protected against external actors. (Arlbjørn and Haug, 2010)

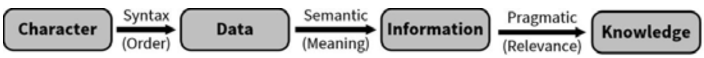

Figure 1: Interconnection between data, information and knowledge (Auer, 2008)

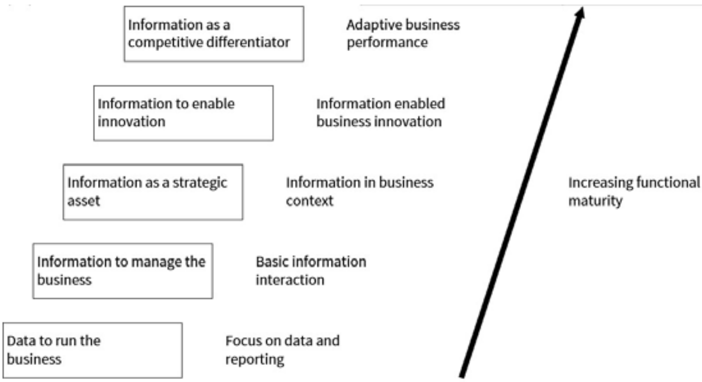

Figure 2: Business Information Maturity Model (Arlbjørn and Haug, 2010)

2.3 Big and Smart Data Analytics

(Provost and Fawcett, 2013) define "Big Data as 'datasets that are too large for traditional data-processing systems and that therefore require new technologies". Therefore big data is mainly produced by machines and thus often represented as machine data, too. According to (Cooper M., 2012) 'Big data is where the data volume, acquisition velocity, or data representation limits the ability to perform effective analysis using traditional relational approaches or requires the use of significant horizontal scaling for efficient processing." Such views focus on the data domain and are therefore insufficient to cover all topics faced in managing Production logistics processes, as for example complexity or analyzing the data gathered is not covered in the definitions above. In order to connect the different characteristics of Big Data to Production logistics the mentioned view needs to be expanded further creating an integrated view of the topic, which includes dependencies of characteristics, business intelligence, statistics, data and characteristics clustering (Wu, Buyya and Ramamohanarao, 2016; Lee, 2017). In doing so the characteristics of Big Data can be clustered in three domains. (Wu, Buyya and Ramamohanarao, 2016)

Data Domain

The Data Domain covers the Variety, Velocity and Volume of Big Data. (Wu, Buyya and Ramamohanarao, 2016) Volume measures the amount of data an organization generates and has already generated, Velocity measures the speed of data generation and Variety measures the different types of data accessible to potential analysis. (Kaisler, et al., 2013) These characteristics cover the descriptions of Provost and Fawcett as well as Cooper's and Mel's view of the subject.

Statistics Domain

The Statistics Domain covers Veracity, Validity and Variability. The characteristics cover issues in data quality, reliability, complexity, variation, decay and data uncertainty. (Wu, Buyya and Ramamohanarao, 2016)

Business Intelligence Domain

The Business Intelligence Domain includes the topics of Visibility, Verdict and Value. (Wu, Buyya and Ramamohanarao, 2016) By adding such characteristics views on decision making, value of data for the business namely extracting valuable information and data hindsight, insight and foresight are also covered. (Wu, Buyya and Ramamohanarao, 2016)

Integrating all characteristics implies that they cannot be viewed independently from each other. (Lee, 2017) Increases in volume, variety and velocity increase complexity, variability and value but decrease veracity. (Lee, 2017) In order to develop a process model, all aspects need to be considered accordingly as the goal is to ensure a lasting integration of Big Data into business processes in production logistics.

Additionally, the topic of value must be further investigated. Big Data itself does not necessarily generate value for the company. The generated information must be presented, aligned with current processes, kept safe, enhanced with previous experiences and aggregated accordingly in order to enable human interactors to decide based on results efficiently and effectively. (Reich R., Mohanty S., Litzel N.; Kaisler, et al., 2013; Coffey L., 2014; Heuring W., 2015; Jähnichen S., 2015; Diesner M., 2016) Big Data Analytics becomes Smart Data Analytics. Smart Data Analytics thus requires also to consider information management aspects which deepen the information process view perspective to be able to manage the information and the consequent distribution of such generated insights by data analysis processes. Additionally, the connection with smart data analytics and supply chain management has to be clarified in order to elaborate potential benefits of data mining and data analytics in supply chains.

2.4 Supply Chain Analytics

Applying smart data in supply chains or production logistics domain results in supply chain analytics which are defined by applying big data and data analytics in the context of logistics and supply chains. (Wang, et al., 2016) Additionally Supply Chain Analytics can be seen as dynamic capabilities of a company. (Chae and Olson, 2013) These capabilities are analytical, IT-enabled, improve supply chain performance. (Chae and Olson, 2013) They consist of a data management, an analytical supply chain process and a supply performance management capability. (Chae and Olson, 2013) These capabilities are necessary to gain useful information and knowledge from supply chain data. (Chae and Olson, 2013) The use of the gathered information and knowledge results in optimized operational, tactical and strategic decisions in the plan-, source-, make-, deliver- and return-phases of supply chains. (Souza, 2014) The necessary analytics-capabilities can be divided into four sections: generating information, insights, decisions and actions (Sivarajah, et al., 2017) These sections are (Sivarajah, et al., 2017):

Descriptive analytics Descriptive analytics provide a basis to understanding what has happened in supply chains.

Inquisitive/diagnostic analytics Diagnostic analytics generate insight into why the results derived in the descriptive phase have occurred.

Predictive analytics Predictive analytics is based on the complete understanding of past events generated in the descriptive and diagnostic phase and based on these findings anticipates future events within certain statistical boundaries.

Prescriptive analytics Prescriptive analytics provides a basis to decision-making processes helping decision-makers gain objective and transparent views on historical events in combination with results from the predictive phase. Questions like ””What now ?” can be answered

Pre-emptive analytics This step recommends based on the decisions made possible courses of action to prevent certain events derived in the predictive phase.

The application and implementation of supply chain analytics must be measured to derive measures for each stage to take in order to apply supply chain analytics most efficiently and effectively to improve business processes. (Arunachalam, Kumar and Kawalek, 2017) The proposed methodology by Arunachalam, Kumar and Kawalek (2017) for measuring divides the capabilities of supply chain analytics in analytics, visualization, data-driven culture, data generation and data integration. Measuring all these capabilities the following stages are identified in Figure 3. (Arunachalam, Kumar and Kawalek, 2017)

Companies must therefore initiate supply chain analytics with data gathering and being able to understand past events of internal supply chains with data. (Initiation stage) This must then be expanded to predictions inside internal supply chains and the inclusion of external data. (Adoption stage) The routinization stage consists of generating knowledge and value of the derived information effectively turning data into a competitive advantage. The stages in figure 3 show that data and analytics capabilities go hand-in-hand in order to derive information, knowledge and value from data.

2.5 Information Management Models

Information Management Models aim to provide reference activities to define one possible efficient and effective way of managing the resource information in organizations. (Krcmar, 2015) There exist some well described Information Management Models, whereas everyone has its individual focus. Three different approaches are (Stahlknecht and Hasenkamp, 2002), Heinrich L. J., Stelzer D. (2011) and Mertens, et al. (2012). Stahlknecht and Hasenkamp (2002) focus on Information as the third production factor and concentrate on the technical information acquisition and storage. Mertens, et al. (2012) also address the technical focus. Heinrich L. J., Stelzer D. (2011), however, focus on the management aspects of information management and aims to establish an information management infrastructure that supports decision-making. In the context of this paper only the model of Krcmar (2015) is analysed in detail as it covers all characteristics mentioned with smart data. Krcmar's model divides information management in four sections. These are executive activities, information economics (demand, supply and consumption), software management and hardware management. (Krcmar, 2015) These sections respectively include: (Krcmar, 2015)

Executive activities Such activities include strategic aspects of information management, IT-Governance, information processes, human resources, financial controlling and IT-Security.

Information economics Information economics activities result in exact knowledge of information demand, information supply and by consequently combining the two deducting the necessary information use of the organization.

Software and hardware management These activities ensure that life-cycles of applications and hardware are generated, maintained and observed. Additionally these sections ensure that the data necessary to satisfy demand is supplied in the most efficient and effective manner possible.

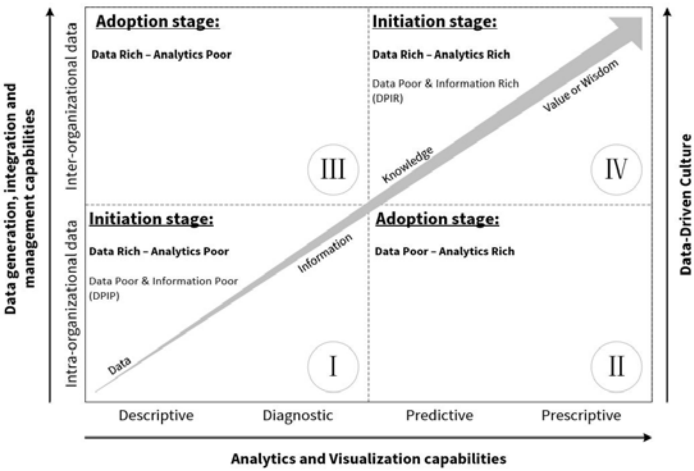

Figure 3: Supply Chain Analytics capability framework (Arunachalam, Kumar and Kawalek, 2017)

The presented information model does not include a section relevant to the creation of value for the organization based on the information provided. Therefore the current landscape on big data reference process models must also be analyzed in depth.

2.6 Big Data and Knowledge discovery process reference models

In order to work with Big Data and master its characteristics certain process steps need to be considered in order to create knowledge about one specific domain. Furthermore the analytics perspective needs to be incorporated into Big Data in order to consider that identified patterns are transformed in usable process knowledge. Such processes can be summarized by the concept of Knowledge Discovery in Databases. (Fayyad, U., Piatetsky-Shapiro G., Smyth G. P., 1996) The academic world and industries alike have developed different kinds of approaches on how and what to face when trying to gain knowledge out of data. The concepts analyzed in the context of this paper are:

- Knowledge Discovery in Databases (KDD) Process
  (Fayyad, U., Piatetsk-Shapiro G., Smyth G. P., 1996).
- Information Flow in a Data Mining Life Cycle
  (Ganesh, et al., 1996; Kopanakis I., 1999).
- SEMMA
  (SAS Institute Inc, 1997)
- Refined KDD paradigm
  (Collier, K., Carey, B., Grusy, E., Marjaniemi, C., Sautter, D., 1998).
- Knowledge Discovery Life Cycle (KDLC) Model
  (Lee and Kerschberg, 1998).
- Cross-Industry-Standard Process for Data Mining (CRISP-DM)
  (CRISP-DM Consortium, 2000).
- RAMSYS
  (Moyle; Blockeel and Moyle, 2002).
- Generic Data Mining Life Cycle (DMLC)
  (Hofmann, 2003; Hofmann and Tierney, 2009).

— Ontology Driven Knowledge Discovery Process (ODKD)
(Gottgtroy, 2007).

— Adaptive Software Development-Data Mining (ASD-DM) Process Model
(Alnoukari, Alzoabi and Hanna, 2008).

— A Data Mining & Knowledge Discovery Process Model
(Marbán Ó, Mariscal G., Segovia J., 2009).

— AgileKDD
(Nascimento G., 2012).

— Big Data Analytics Activity Reference Framework
(Yew, 2015).

— Knowledge Discovery in Data Science
(Grady, 2016).

All mentioned methodologies focus on the data mining tasks and only partially consider how to transfer the knowledge gathered into the organization. Furthermore, all methodologies presume that all process steps are performed as projects and not continuous improvement tasks to optimize business processes constantly. Additionally, no explicit loops are considered to stop the cycle once it becomes evident that with the current quality and availability of prerequisites such as data itself for example the project needs to be modified and transformed into a change process. This process then aims to transform the involved business processes in such a manner that they fulfill the prerequisites and provide the basis to improve business processes with data mining and knowledge discovery methods. Pivk, A., Vasilecas O., Kalibatiene D., Rupnik R.(2013) propose a methodology to use data mining to optimize business processes. Adapting processes to incorporate gathered knowledge is being considered, yet this model does propose to perform loops when required, certain prerequisites are not met or model deployment uncovers possible changes necessary to business processes in order to perform optimizations with data mining and knowledge discovery in databases.

3 Extension of existing approaches to data mining and knowledge discovery in databases

In order to solve the weaknesses mentioned above, a combination of the AgileKDD model, the Generic Data Mining Life Cycle, the Data Mining & Knowledge Discovery Process Model by Marban (2009), the proposed implementation of datamining to perform business process optimization (Pivk, A., Vasilecas O., Kalibatiene D., Rupnik R., 2013), the Knowledge Discovery in Data Science approach (Grady, 2016), the Big Data Analytics Activity Reference Framework (Yew, 2015) and Krcmar's Information Management Model (Krcmar, 2015) is proposed. Combining these models, the following reference activities must be incorporated when trying to derive a process reference model suitable to integrate knowledge discovery results into business processes under the aspect of performing loops when prerequisites of stages are not met:

— Identify potentials in business processes where data mining activities can improve performance. (Identify potentials)

— Provide a transparent and decisive process to evaluate benefits and necessary resources for chosen activities ideally expressed in monetary units. (Benefits)

— Apply traditional data mining activities which potentially can generate necessary knowledge to realize identified performance improvements based on a predefined selection matrix customized to production logistics needs. (Data Mining)

— Apply chosen techniques within a standardized environment mainly consisting of a big-data-platform which provides all necessary hardware, software, a knowledge repository documenting previous activities, a model repository documenting previous modelling approaches and access to various data sources in a timely manner. (Deployment)

— Continuously evaluate the progress of activities related to all necessary steps to allow modifications to previous steps once disrupting events are uncovered during the execution of tasks. (Evaluation)

— Provide suitable organizational methods and means to preserve the generated knowledge, share it across the organization and ensure experiences made in the application of the results are considered in future iterations of the process. (Integration)

These steps are only to be executed with an implemented and fully operational big-data platform allowing the use of standardized hardware, software, scaling, interfaces, data sources, knowledge repositories, model repositories, data governance protocols, privacy protection and security measures.

The ”identify potentials”-phase consists of a thorough analysis of the business processes to be improved with a focus on the information flows and the consequent tasks mainly triggered by generated information during the execution of the processes. Such focus is necessary as the model aims to optimize information flows and due to the focus on information all data understanding topics are also covered. This phase can be compared to Hofmann’s phase of constantly looping through the business understanding and data preparation phase until the understanding of both domains is sufficient to set the objectives and hypothesis clearly to proceed with data processing. (Hofmann, 2003) Furthermore as the objective is to optimize the process a change process must be conceived once the desired results are generated. This aspect also incorporates the Assessment- and Business-Process-Renovation-phase in the proposed approach of (Pivk, A., Vasilecas O., Kalibatiene D., Rupnik R., 2013) excluding application analysis, design, development and design. Additionally, the first six steps of the Big Data Analytics Activity Reference Framework by Yew (2017) are considered.

The benefits-phase determines the necessary resources to optimize the chosen business processes with supply chain data analytics and weigh them against potential benefits gained from the generated insight of the knowledge discovery process. This step mainly incorporates Marban’s (2009) approach to data mining where software engineering and project management practices are incorporated. (Marbán Ó, Mariscal G., Segovia J., 2009) If the benefits-process is triggered by the processes downstream the necessary changes to be made must be assessed and weighted against the resources necessary to implement them.

The Data Mining phase consists of the core Knowledge Discovery process covering data transformation, pre-processing, choosing suitable data mining techniques, developing a model, apply the model and evaluate results. (CRISP-DM Consortium, 2000; (Marbán, et al., 2007)

The deployment-phase consists of adequately scaling the results and the model to suit the business process to be optimized within the limits of the platform.

Furthermore, the generated model and the gathered knowledge are to be transferred to the respective repositories on the platform resembling the steps in the Hofmann (2003) approach.

The evaluation- phase covers the maintenance and monitoring of the deployed solution and should verify the benefits derived in the identify-potentials-phase. The focus should be put on the improvement of decision-making based on the generated knowledge. It can also be considered as a pilot-implementation-phase.

The last step consists of integrating the improved process into the organization by developing a roll-out-plan which consists of activities in the Integral process domain cited in Marbán's model. (Marbán Ó, Mariscal G., Segovia J., 2009) These are, for example, training of employees or create a documentation.

The loops in shown in Figure 4 allow for the mentioned weakness of transforming the process into a change process to ensure the readiness of the process to incorporate data mining as an improvement tool. This change process is then started during the benefits phase if the potential benefit is sufficient to justify the necessary changes in business processes. The change process can be triggered in various other phases of the model.

The model therefore enables companies by repeatedly executing the steps to build up their supply chain analytics capabilities and steadily implement truly data-driven supply chains as it can be applied in the four stages of Supply Chain analytics and because of the loops dynamically adapted to suit the needs in every phase.

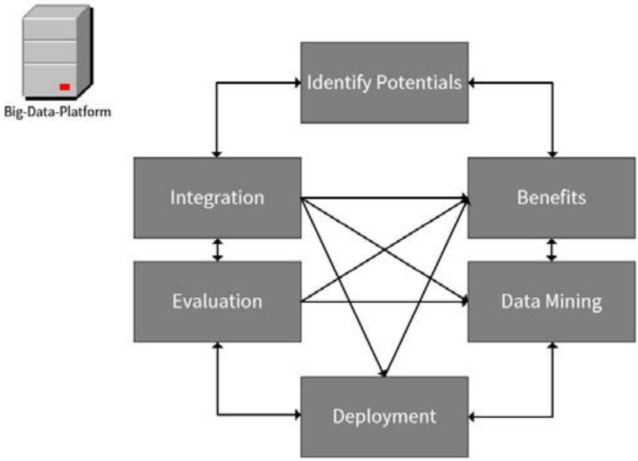

Figure 4: Knowledge Discovery Model for Production Logistics

4 Application in the automotive supplier industry

The developed model was applied in cooperation with a large international automotive supplier with the goal to integrate data mining and knowledge discovery in databases within its production logistics of the electronics manufacturing domain.

The framework was developed while trying to integrate data analytics in business process in the plan-, soure-, make- and delivery-domains with current methods mentioned in Section 3. During the application of the methods the mentioned weaknesses became evident resulting in the development of the new reference model. The application of the model to the use-cases is still ongoing.

Currently the focus is to thoroughly define, implement and the ”Identify potentials”- and ”Benefits”-phases of the model. The ”Identify potentials”-phase in the application domain consists of a combination of three approaches to systematically determine possible applications of Supply Chain Analytics. These are:

1. Interviews

   The first and currently most used approach is to interview managers about current issues regarding information deficits and labor-intensive processes necessary to provide the organization with decision-relevant information. The results are then evaluated and processed in order to determine if theoretical benefits can be generated by applying descriptive analytics, diagnostic-, predictive-, prescriptive- or pre-emptive analytics. The general rule currently being applied is that possible use-cases only generating descriptive insight are not being pursued as this kind of activity is mostly connected to reporting-topics which require a completely different kind of methodological approach. If theoretical benefits are found, the next process step can be started.

2. Process analysis

   As a prerequisite possible processes suitable for improvement must be chosen. This requires a rather superficial and fast way to analyze processes. In the automotive context the SIPOC-approach was chosen. The approach consists of describing the supplier, input, process, output and customer in a very short and precise way. (Toutenburg and Knöfel, 2009).

Based on the rough process analysis inefficiencies and optimization potentials are then identified. These inefficiencies and potentials are then evaluated by the possible benefits of the application of data analytics. The focus is to be laid on the input, output, suppliers and customers as the knowledge generated by the application of data analytics can either help to improve the information content of input/output or help to better understand the behavior of the customer/supplier. If the SIPOC-analysis has generated promising potentials a more detailed analysis of the process to be improved can be started.

This step requires a precise documentation of processes ideally using the BPMN-notation, as this notation also includes data flows. These flows provide basis for an analysis based on information management principles and by determining deviations of the current state to the target picture. The deviations are then further investigated in order to determine if the application of analytics-tools provides an improvement leading to a decrease of the determined deviation. If the reduction is deemed sufficient enough the next process step of the model can be started.

3. Benchmarking

   Benchmarking activities in this context include extensive literature research and the compilation of locally implemented data-analytics solutions within the manufacturing network of the company. These two views must then be combined, generating a view on the subject containing internal and external activities. This view must then be used to determine possible use-cases using data analytics in a workshop with operational management.

   Once possible use-cases are determined a benefit analysis is conducted in order to determine the economic benefits. This benefit analysis contains qualitative and quantitative aspects.

   The qualitative aspects include compliance improvements, conformance improvements, decision-making basis improvements, increase in transparency, analytics maturity and risks regarding goal-achievements. The analytics maturity is evaluated using the desired data analytics level (descriptive-, diagnostic-, predictive-, prescriptive-, pre-emptive analytics). The further the use-case advances the higher the evaluation.

   The quantitative aspects include rough estimates regarding costs of development, implementation and maintenance. The costs are then compared against possible cost savings and performance improvements. Furthermore the qualitative aspects are included into the cost-saving-calculation with a factor.

No conclusive results can be presented at this moment in time, yet the approach of aligning data analytics activities with the available resources of the platform and implemented business processes has rendered great acceptance of the proceeding within the affected parts of the organization and first pilot-phases have shown great potential to transform production logistics into a data-driven endeavor seamlessly integrateable in other Industry-4.0-activities within the company. Furthermore, the operational, tactical and strategic decisions are already partially based on the results of the pilots which are now based on knowledge previously unused resulting in focusing available resources more efficiently and effectively on current business challenges. These changes in resource allocation are now used to proactively uncover potential disruptions to processes avoiding fire-fighting and task-forces activities.

5 Conclusion

The presented supply chain analytics and knowledge discovery model does by design align with current business processes and therefore can seamlessly be integrated into current continuous improvement activities which facilitates the acceptance of data analytics solutions among all parties involved. No definitive results can be presented at this time to prove the effectiveness and efficiency of the model in the context of production logistics. Current results of the running pilots have the desired managerial implications of being able to allocate resources to proactively discover and counteract potential process disruptions which can be discovered by data-based decisions enabled by the application of the presented knowledge discovery model. Information can then be used as a competitive differentiator. Furthermore the first two steps of the model have been systematically applied with success in order to determine possible pilot use-cases to test and develop the model further.

The model does have its limitations as the application has been limited to in-house supply-chain-processes in the automotive supplier industry. The implementation of the model does proceed accordingly, yet only the first two steps in the model have been thoroughly defined and applied to real-world applications. The other steps are currently highly theoretical and in pilot phases. Further research has to be performed to specify the remaining processes in the model more thoroughly in order to make them applicable to other domains in supply chain management. Additionally, the platform needs to be specified further.

References

Alnoukari, M., Z. Alzoabi, and S. Hanna (2008). “Applying adaptive software development (ASD) agile modeling on predictive data mining applications: ASD-DM methodology”. In: *2008 International Symposium on Information Technology*. IEEE, pp. 1–6.

Altendorfer-Kaiser, S. (2015). “Information Logistics Means to Support a Flexible Production?” In: *Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth*. Ed. by S. Umeda, M. Nakano, H. Mizuyama, N. Hibino, D. Kiritsis, and G. von Cieminski. Vol. 459. IFIP Advances in Information and Communication Technology. Cham: Springer International Publishing, pp. 414–421.

Arlbjørn, J. S. and A. Haug (2010). *Business process optimization*. 1. edition. Århus: Academica.

Arnold, D. (2006). *Intralogistik*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Arunachalam, D., N. Kumar, and J. P. Kawalek (2017). “Understanding big data analytics capabilities in supply chain management: Unravelling the issues, challenges and implications for practice”. In: *Transportation Research Part E: Logistics and Transportation Review*.

Auer, T. (2008). “Wissensmanagement: Reizwort oder zeitgemäße Notwendigkeit ?” In: *Controller Leitfaden* 12.

Bali, R. K., N. Wickramasinghe, and B. Lehaney (2009). *Knowledge management primer*. Routledge series in information systems. New York and London: Routledge.

Blockeel, H. and S. Moyle (2002). “Collaborative data mining needs centralised model evaluation”. In: *Proceedings of the ICML-2002 Workshop on Data Mining Lessons Learned*, pp. 21–28.

Bolstorff, Peter A., Rosenbaum, Robert G., Pohula, Rolf G. (2007). *Spitzenleistungen im Supply Chain Management*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Chae, B. and D. L. Olson (2013). “Business analytics for supply chain: a dynamic-capabilities framework”. In: *International Journal of Information Technology & Decision Making* 12.01, pp. 9–26.

Coffey L. (2014). *Smart Data - What is it & How it is Different From Big Data?*

Collier, K., Carey, B., Grusy, E., Marjaniemi, C., Sautter, D. (1998). *A perspective on Data Mining*. Ed. by Center for Data Insight. USA.

Cooper M., M. P. (2012). *Tackling Big Data*. Ed. by Federal Computer Security Managers’ Forum. USA.

Corte-Real, N., T. Oliveira, and P. Ruivo (2017). “Assessing business value of Big Data Analytics in European firms”. In: *Journal of Business Research* 70, pp. 379–390.

CRISP-DM Consortium (2000). *CRISP-DM 1.0: Step-by-step data mining guide*.

Diesner M. (2016). “Massendaten im Fertigungsumfeld”. In: *visIT[Big Data] - Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung IOSB*, pp. 6–7.

Fayyad, U., Piatetsky-Shapiro G., Smyth G. P. (1996). “From data mining to knowledge discovery in databases”. In: *AI Magazine*, pp. 37–54.

Fosso Wamba S., Akter S. (2015). “Big data analytics for supply chain management: A literature review and re-search agenda”. In: *Enterprise and Organizational Modeling and Simulation*, pp. 61–72.

Ganesh, M., E.-H. Han, V. Kumar, S. Shekhar, and J. Srivastava (1996). *Visual Data Mining: Framework and Algorithm Development*.

Gimenez Isasi, N. K., E. Morosini Frazzon, and M. Uriona (2015). “Big Data and Business Analytics in the Supply Chain: A Review of the Literature”. In: *IEEE Latin America Transactions* 13.10, pp. 3382–3391.

Gottgtroy, P. C. M. (2007). “Ontology Driven Knowledge Discovery Process: A proposal to integrate Ontology Engineering and KDD”. In: *PACIS*.

Grady, N. W. (2016). “KDD meets Big Data”. In: *2016 IEEE International Conference on Big Data (Big Data)*. IEEE, pp. 1603–1608.

Günther, H.-O. and H. Tempelmeier (2014). *Supply Chain und Operations Management*. 11., verbesserte Auflage. Vol. / Horst Tempelmeier; Hans-Otto Günther ; [Hauptbd.] Produktion und Logistik. Norderstedt and Norderstedt: Books on Demand.

Heinrich L. J., Stelzer D. (2011). *Informationsmanagement*. Oldenburg: Oldenbourg Wissenschaftsverlag.

Heuring W. (2015). *Warum Big Data zu Smart Data werden muss!*

Hofmann, M. (2003). “The development of a generic data mining life cycle (DMLC)”. Ph. D. Ireland: School of Computing.

Hofmann, M. and B. Tierney (2009). “An enhanced data mining life cycle”. In: *2009 IEEE Symposium on Computational Intelligence and Data Mining*. IEEE, pp. 109–117.

IARIA, ed. (2012). *The Seventh International Conference on Software Engineering Advances*.

Jähnichen S. (2015). “Von Big Data zu Smart Data – Herausforderungen für die Wirtschaft”. In: *Newsletter Smart Data August 2015*, pp. 1–2.

Jamil, G. L., A. L. Soares, and C. R. M. Pessoa (2017). *Handbook of Research on Information Management for Effective Logistics and Supply Chains*. IGI Global.

Kaisler, S., F. Armour, J. A. Espinosa, and W. Money (2013). “Big Data: Issues and Challenges Moving Forward”. In: *2013 46th Hawaii International Conference on System Sciences*. IEEE, pp. 995–1004.

Kopanakis I., T. B. (1999). “Visual data mining & modeling techniques”. In: *University of Manchester Institute of Science and Technology - Department of Computation*.

Krcmar, H. (2015). *Informationsmanagement*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Krieger W. (2017). *Definition Produktionslogistik*. Ed. by Gabler Wirtschaftslexikon.

Lee, I. (2017). “Big data: Dimensions, evolution, impacts, and challenges”. In: *Business Horizons* 60.3, pp. 293–303.

Lee, S. W. and L. Kerschberg (1998). “A methodology and life cycle model for data mining and knowledge discovery in precision agriculture”. In: *SMC’98 Conference Proceedings. 1998 IEEE International Conference on Systems, Man, and Cybernetics (Cat. No.98CH36218)*. IEEE, pp. 2882–2887.

Leveling, J., M. Edelbrock, and B. Otto (2014). “Big data analytics for supply chain management”. In: *2014 IEEE International Conference on Industrial Engineering and Engineering Management*. IEEE, pp. 918–922.

Marbán Ó, Mariscal G., Segovia J. (2009). “A Data Mining & Knowledge Discovery Process Model”. In: *Data Mining and Knowledge Discovery in Real Life Applications*. Ed. by K. A. Ponce J. I-Tech Education and Publishing, Ch. 1.

Marbán, Ó., G. Mariscal, E. Menasalvas, and J. Segovia (2007). “An Engineering Approach to Data Mining Projects”. In: *Intelligent Data Engineering and Automated Learning - IDEAL 2007*. Ed. by H. Yin, P. Tino, E. Corchado, W. Byrne, and X. Yao. Vol. 4881. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 578–588.

Mertens, P., F. Bodendorf, W. König, A. Picot, M. Schumann, and T. Hess (2012). *Grundzüge der Wirtschaftsinformatik*. 11. Aufl. 2012. Springer-Lehrbuch. Berlin, Heidelberg: Springer Berlin Heidelberg and Imprint: Springer.

Meudt, T., M. P. Rößler, J. Böllhoff, and J. Metternich (2016). “Wertstromanalyse 4.0”. In: *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb* 111.6, pp. 319–323.

Militaru, G., M. Pollifroni, and A. Ioanid (2015). “BIG DATA IN SUPPLY CHAIN MANAGEMENT: AN EXPLORATORY STUDY”. In: *Network Intelligence Studies* 6, pp. 103–108.

Moyle, S. (n.d.). “RAMSYS - A methodology for supporting rapid remote collaborative data mining projects”. In:

Nascimento G., O. A. (2012). “AgileKDD: An Agile Business Intelligence Process Model”. In: *The Seventh International Conference on Software Engineering Advances*. Ed. by IARIA, pp. 598–604.

Pivk, A., Vasilecas O., Kalibatiene D., Rupnik R. (2013). *On approach for the implementation of data mining to business process optimisation in commercial companies*. The Free Library.

Ponce J., K. A., ed. (2009). *Data Mining and Knowledge Discovery in Real Life Applications*. I-Tech Education and Publishing.

Provost, F. and T. Fawcett (2013). *Data science for Business: What you need to know about data mining and data-analytic thinking*. First edition. Sebastopol, Calif.: O’Reilly.

Reich R., Mohanty S., Litzel N. (n.d.). *Nach Big Data kommt Smart Data*.

SAS Institute Inc (n.d.). *SEMMA: Data mining and the case for sampling*. SAS Institute Inc.

Schöning H., D. M. (2017). “Big Smart Data – Intelligent Operations, Analysis und Process Alignment”. In: *Handbuch Industrie 4.0 Bd.2*. Ed. by B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel. Springer Reference Technik. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 457–469.

Schuh, G., S. Krumm, and W. Amann (2013). *Chefsache Komplexität*. Wiesbaden: Springer Fachmedien Wiesbaden.

Sivarajah, U., M. M. Kamal, Z. Irani, and V. Weerakkody (2017). “Critical analysis of Big Data challenges and analytical methods”. In: *Journal of Business Research* 70, pp. 263–286.

Souza, G. C. (2014). “Supply chain analytics”. In: *Business Horizons* 57.5, pp. 595–605.

Stahlknecht, P. and U. Hasenkamp (2002). *Einführung in die Wirtschaftsinformatik*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Supply-Chain Council (2008). *Supply-Chain Operations Reference-Model Version 8.0*. Pittsburg, USA.

Toutenburg, H. and P. Knöfel (2009). *Six Sigma: Methoden und Statistik für die Praxis*. 2., verbesserte und erweiterte Aufl. Berlin and Heidelberg: Springer.

Uckelmann, D. (2012). *Quantifying the Value of RFID and the EPCglobal Architecture Framework in Logistics*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Umeda, S., M. Nakano, H. Mizuyama, N. Hibino, D. Kiritsis, and G. von Cieminski, eds. (2015). *Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth*. IFIP Advances in Information and Communication Technology. Cham: Springer International Publishing.

Vogel-Heuser, B., T. Bauernhansl, and M. ten Hompel, eds. (2016). *Handbuch Industrie 4.0 Bd.3: Logistik*. Wiesbaden: Springer Science and Business Media and Springer Vieweg.

Vogel-Heuser, B., T. Bauernhansl, and M. ten Hompel, eds. (2017). *Handbuch Industrie 4.0 Bd.2: Automatisierung*. Springer Reference Technik. Berlin, Heidelberg: Springer Berlin Heidelberg.

Wang, G., A. Gunasekaran, E. W. Ngai, and T. Papadopoulos (2016). "Big data analytics in logistics and supply chain management: Certain investigations for research and applications". In: *International Journal of Production Economics* 176, pp. 98–110.

Wehberg G. (2016). "Big Data – Mustererkennung als Erfolgsfaktor der Logistik 4.0". In: *Handbuch Industrie 4.0 Bd.3*. Ed. by B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel. Wiesbaden: Springer Science and Business Media and Springer Vieweg, pp. 377–392.

Wu, C., R. Buyya, and K. Ramamohanarao (2016). "Big Data Analytics = Machine Learning + Cloud Computing". In: *CoRR* abs/1601.03115.

Yew, S. L. B. (2015). "Building use Cases With Activity Reference Framework for Big Data Analytics". In: *2015 9th International Conference on IT in Asia (CITA)*. IEEE, pp. 1–7.

Zhang, Y., S. Ren, Y. Liu, T. Sakao, and D. Huisingh (2017). "A framework for Big Data driven product lifecycle management". In: *Journal of Cleaner Production* 159, pp. 229–240.

Zhang, Y., S. Ren, Y. Liu, and S. Si (2017). "A big data analytics architecture for cleaner manufacturing and maintenance processes of complex products". In: *Journal of Cleaner Production* 142, pp. 626–641.

Use Case of Self-Organizing Adaptive Supply Chain

Julia Wagner[1], Henning Kontny [1]

1 – HAW Hamburg

The main drivers for the development and implementation of self-organizing adaptive operation processes are the increase of flexibility while lowering costs in times of growing consumer demands, shaping the supply chain into "the source of enterprises core competence". This paper is based on the "Guidelines for conducting and reporting case study research in software engineering" and it demonstrates the design of the self-organizing adaptive supply chain through an integration of processes and systems. As a result, the automated near real-time data flow enables shorter order-lead-time with a high accuracy of information. Although the study includes the architecture for the self-organizing adaptive supply chain, it cannot be completely standardized due to individual processes and IT-systems within different companies. Academics and practitioners may find it useful to identify appropriate scenarios while looking for the ways to digitize their supply chains.

Keywords: Self-Organizing Systems; Adaptive Supply Chain; Digitalization; Use Case

1 Introduction

Today's consumers require the products they have ordered to be delivered faster and faster, and innovative products should be offered within shorter and shorter time-to-market cycles. What industry is able to achieve today, will soon be insufficient (Bauernhansl, ten Hompel and Vogel-Heuser, 2014). This expands the role of Supply Chains (SC) to the "source of competitive advantages"(Ponte et al., 2017), considering that they include all the material and information flows as well as processes from sourcing (purchasing), internal activities (manufacturing, assembly, storage etc.) to product shipping. In order to stay competitive and to be able to satisfy growing customer demands, companies are striving toward the application of new IT systems. There are some industries which even completely depend on the IT in supply chains such as the meat industry, where transparency through the shared data between different suppliers and buyers could help to prevent scandals involving meat products (Kassahun, Hartog and Tekinerdogan, 2016). In recent studies the supply chain is viewed as one of the most important criteria for commercial success (Wellbrock, 2015; Yuvaraj and Sangeetha, 2016), which also should be adaptable to changing demands in the interest of potential growth (Bogaschewsky et al., 2016; Fuller et al., 2013) and as a consequence is even called „moving authority" (Plattform Industrie 4.0, 2016).

Nevertheless, small and medium-sized enterprises (SMEs) have rather immature IT-systems along supply chains, despite the fact that they generate around 50% of GDP of developed countries and are responsible for 60% of employment (Kumari et al., 2015). Although SMEs usually have an ERP and production systems, many decisions such as production planning, purchasing volumes for raw materials etc. are usually taken with help of numerous Excel sheets or Access Databases also known as Shadow IT (Rentrop and Zimmermann, 2012; Jones et al., 2004). Other scientists (O'Leary, 2008) underline that around 90% of supply chains are fragmented and not digitalized end-to-end. As a result, the entire process of order fulfillment remains very slow and is vulnerable to mistakes.

At the same time, the vision of the Internet of Things (IoT) or also known as Industry 4.0 is arising, targeting the interconnection of physical objects such as product or a machine with the enterprise systems, allowing companies to collect real-time data as well as to automate simple decisions based on historical data. "The IoT allows things' and 'objects', such as RFID, sensors, actuators, mobile phones, which, through unique addressing schemes, (…) interact with each other and cooperate with their neighboring 'smart' components, to reach common goals"(Dittrich et al., 2008). This leads to a decentralized execution of business processes, thereby increasing process efficiency and transparency.

Research studies underline the need to provide a reference architecture integrating IoT services (Dar et al., 2015) in order to enable the spread of new technologies. Other authors(Gunasekaran et al., 2016; Duan and Xiong, 2015) add that visibility as one of the most important organizational capabilities can "revolutionize existing supply chains". However, as the McKinsey Survey of over 300 industrial companies from the USA, Japan and Germany shows, most enterprises have difficulties in defining a convertible strategy for the implementation of the Industry 4.0 to gain competitive advantages, despite their high interest in doing so. "Digitalization is important, but we are not prepared enough" (McKinsey Digital, 2016).

For these reasons, the main objective of this paper is to describe a process of the development of a Self-Organizing Adaptive Supply Chain based on the case study for a greater understanding of such a complex project.

2 Theoretical Background

2.1 Self-Organizing Adaptive Logistics

Although adaptable processes which allow balanced execution of operations under unstable conditions are in focus of many research articles, the design of such remains little known (Bogaschewsky and Müller, 2016).

The concepts of Self-Organization/Autonomy are used in this case study in the context of an automated data analysis, with an independent reaction to changes, including self-configuration and self-optimization by systems, up to the level of an entire self-organization. This is an indispensable component of the Industry 4.0 or Internet of Things. Examples for self-organizing are the generation of automated procurement orders, control of supplies or consumption of materials etc. (Agiplan GmbH, Fraunhofer IML and Zenit GmbH, 2015). Self-Organizing Adaptive Logistics: "focuses on the entire inter- and intra-logistics structure" in order to increase flexibility and reaction time using efficient data analysis to make better decisions or counteract possible disturbances of processes. It is closely linked to the logic of Order-Controlled Production(Plattform Industrie 4.0, 2016) although it encloses the integration of all operational processes and material movements (End-to-End Supply Chain).

Autonomous logistic components which are capable to communicate among each other will become “Smart Objects”, which are intelligently connected with each other and are able to independently optimize themselves as an adaptive, co-operating group, whose further development will lead to a decentralized self-organized logistics system with complete fusion between the physical and the virtual world (Voß, 2015).Although adaptable processes which allow balanced execution of operations under unstable conditions are in focus of many research articles, the design of such remains little known(Kersten et al., 2015). On the other hand, IBM, Siemens, Cisco and other firms (O’Leary, 2008) underline the need for autonomic systems, arguing that human intervention requires higher costs and longer periods of time.

2.2 Related Work

The estimation of the efficiency of decision-making by human participants in comparison to IT systems has occupied scientists for a long time. Measurable results for such comparison were provided at the XXI International Conference on Industrial Engineering and Operations Management 2015, where scholars (Costas et al., 2017) presented results of an IT system (Agent-Based Modelling and Simulation) playing the well-known Beer Distribution Game. BDG was presented by Sterman (1989) at the MIT Sloan School of Management and is widely used to observe the Bullwhip Effect known from Forrester (1968), which represents one of the basic concepts of Supply Chain Management. Human players were not able to deal with a high-load of information and uncertainties and as a result, they were outperformed by the IT system in every single parameter, which managed to keep a low inventory level ($3,641 IT vs. $21,662 Human decision) in combination with low lost sales ($4 vs. $652).

3 Methods and Approach

3.1 Design of Use Case

The use case was designed according to “Guidelines for conducting and reporting case study research in software engineering”(Runeson and Höst, 2009), which underlines the importance of case studies for investigation of complex issues, especially involving humans in interaction with technology. Case study methodology is closely related to action research (Dittrich et al., 2008; Gorschek et al., 2006), which is focused on change processes such as software process improvement or technology transfer studies. Whereas the analysis of the effects of a change is classified as a case study (Runeson and Höst, 2009). The case study allows to “investigate a contemporary phenomenon within its real-life context”(Shahin, 2015) and represents a comprehensive analysis of several of cases (Waterman, 2014). This paper represents the cumulative results from several projects:

1. Coffee manufacturer, over 2.000 employees, project ”End-to-End digitization of Supply Chain”.
2. LED (light-emitting diode) producing company, over 2.000 employees, focus on digitization of Demand and Supply Chain processes.
3. Manufacturer of air filters and signaling technologies, over 500 employees, project ”Cyber Assembly” focusing on the digitization of assembly, production, warehousing and purchasing.

The above-mentioned projects present the following similarities:

— Focus on the digitization of decision processes and automated data flow.

— Aiming at fast and precise data exchange across at least four independent departments.

— New and/or changes in customer orders trigger the calculation of production, warehouse etc. volumes.

The setup of the use case includes the subsequent steps, which according to Perry et al. (Perry, Sim and Easterbrook, 2004) separate the case study from an experience report:

1. Clearly defined research question

2. Systematic data collection and analysis in order to answer the research question

3.2 Research Question and Data Collection

Due to the high pressure of consumer expectations, it is crucial to understand the requirements of the market and to be able to adapt to them instantly, which leads us to the research question:

What are the main requirements and design principles for the Self-Organizing Adaptive Supply Chain?

As the proper design of the case study needed systematic data collection, it was carried out on the basis of face-to-face interviews as well as through workshops with managers and scholars. The process mapping and development of the target process acquired in each case over ten single interviews (see Table 1) with experts from departments of production, logistics, controlling and planning on national and international levels. The results were documented as event-driven process chains (EPC) on a very detailed level as well as two flow charts on a higher level, each of the process ”as is” and target process. Both EPCs and flow charts were reviewed and if required supplemented during three two-day workshops with the responsible managers. Subsequently, the developed architecture of a current status of processes and systems was confirmed as appropriate by responsible managers. At this stage of the projects, the data was analyzed mainly on a qualitative level in form of process steps, timeline and information flow.

Table 1: Interviews for process mapping.

Company	Timeline	Interviewer	Interviews
Coffee manufacturer	10/2011 – 12/2011	First Author, external Consultant	14
LED producer	11/2013 – 04/2014	First Author	23
Manufacturer of air filters	09/2016 – 12/2016	Both Authors	12

In pursuance of a development of a robust target process, the method of the "operation recording" (Herrmannsdoerfer and Koegel, 2010; Lippe and Van Oosterom, 1992; Langer et al., 2013) was adopted – which is a documentation of the processes within the modelling environment, while the processes are actually being performed.Subsequently, the developed architecture of a current status of processes and systems was confirmed as appropriate by company executives.

3.3 Process Mapping

In order to document and present the results of data collection in a structured and comprehensible way the concept of Enterprise Architecture was chosen, which is according to Ross (2006), includes business processes and IT infrastructure in order to fulfill long-term operation needs as well as to plan the projects. ISO/IEC/IEEE defines an architecture "as composed of: (a)the fundamental organization of a system embodied in its components; (b) their relationships to each other, and to the environment; and (c) the principles guiding its design and evolution."(ISO/IEC 42010: 2007-Systems and software engineering–Recommended practice for architectural description of software-intensive systems, 2007). Other scholars (Tekinerdogan, 2014) add that a software architecture represents the structure of the systems on a high-level and is relevant for the stakeholder communication, design decisions including the planning of implementation project and allocation of tasks.

In this way, the study supports the IT experts with the business knowledge that is necessary for the supply chain digitalization. Although IT units primary knowledge is technical, it is essential that IT managers understand the potential challenges for the SC digitalization from a business perspective (Xue, 2014), which leads to more effective communication between IT and operation departments and thus better results for the development projects.

4 Architecting the Self-Organizing Adaptive Supply Chain

4.1 Case Description

Company X is a typical medium-sized enterprise with a business model of purchasing raw materials from outside and executing operations in-house (Kumari et al., 2015), then selling products to diverse customers (as shown in Material Flow in figure 1). For example, a coffee company would buy green coffee beans, roast them (equal to the “pre-production” process step), blend the beans and pack them in diverse types of packaging in units of 1000g, 500g or 250g (equal to “production planning 2” step as shown in figure 1). As with many SMEs, company X had no in-house consulting or a strategic IT department. Subsequently, the business grew over the years, but supporting systems stayed at the same level as of their implementation over ten years ago. In contemplation of significant increase of customer demand other production locations with additional warehousing were acquired. Despite additional production capacity, the order-lead-time (time between the customer order and delivery of the order) was not shortened. In times, where Amazon and other “Big Players” offer very short delivery times, order-lead-time became one of the critical factors of success in the consumer market. For these reasons, the main aim of the project was to provide the IT solution for an adaptive supply chain with the following targets:

- End-to-end digitalization of data along the supply chain
- Shorter order-lead-time (from over 2 weeks to 1 week)
- Lower level of inventory (reducing the average 4-6 week safety stock to 2 weeks)

4.2 Adaptive Supply Chain Architecture

The approach of the visualizing of existing business processes and systems was based on principles presented by Panunzio (Panunzio and Vardanega, 2014), who underlines that software architecture:

- Should stay at a high-level, “does not pollute”
- And at the same time “meaningfully represents those entities and their semantics”.

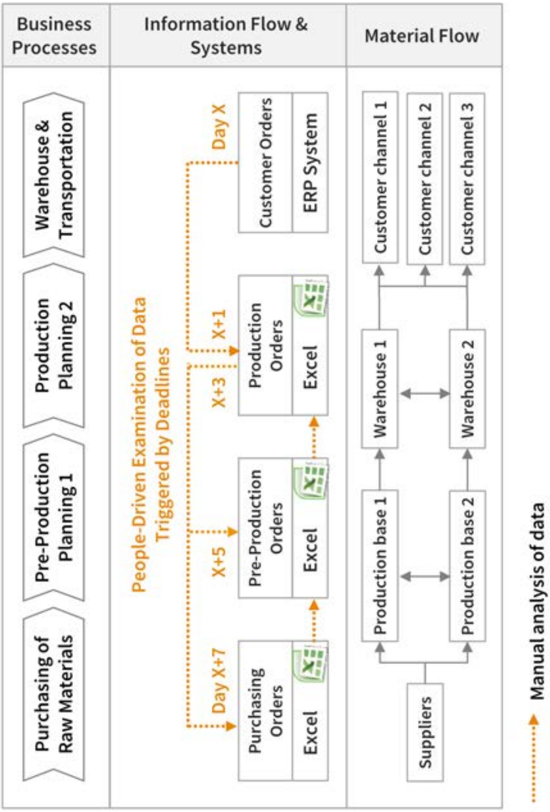

Figure 1: Operational Processes ”As Is”

For these reasons the Enterprise Architecture was structured into the three most important levels:

- High-level business processes (which also match the organizational structure of departments)
- Information flow including systems used for decision-making
- Material flow from suppliers to customers.

Based on numerous face-to-face interviews the first version of the Enterprise Architecture “As Is” was created (the processes outside the supply chain such as finance, marketing etc. were left out of scope). It showed that although the ERP system contains all the information about articles such as master data, bill of material, the information about customers and suppliers; the relevant decisions on volume of orders, evaluation of supplier performance (at purchasing departments) and production planning (in production departments) were still met based on diverse reports exported into Excel. This way of working caused a very slow reaction by the company to the changes in customer orders (as shown in figure 1). Additionally, the data in different departments had different levels of accuracy in comparison to the real-time data. For example, the production orders for Monday in the production system were based on data from Thursday of the last week, whereas pre-production operations were lagging even further behind. The purchasing department, which purchases the raw materials, takes that decision not based on actual customer orders (they will still be taken into a consideration), but on the information from production, thus creating additional waiting time. All these facts lead to the conclusion, that the more participants, who change the data and need 1-3 days for the alignment with others, a process has, the longer the order-lead-time will be.

The next step was the planning and execution of workshops with managers of respective departments who are responsible for business processes. As a result, all participants agreed that the current IT systems do not provide the required level of support to the processes and should be improved. The material flow was left out-of-scope for the target architecture because the increase in its complexity over recent years due to new production bases and warehouse as well as an additional customer channel had no significant impact on the structure of the processes or systems. Considering that the decision-making process for the production, pre-production and purchasing of goods took over 50% of the order-lead-time, it was agreed to automate those calculation processes without substantial changes in material flow.

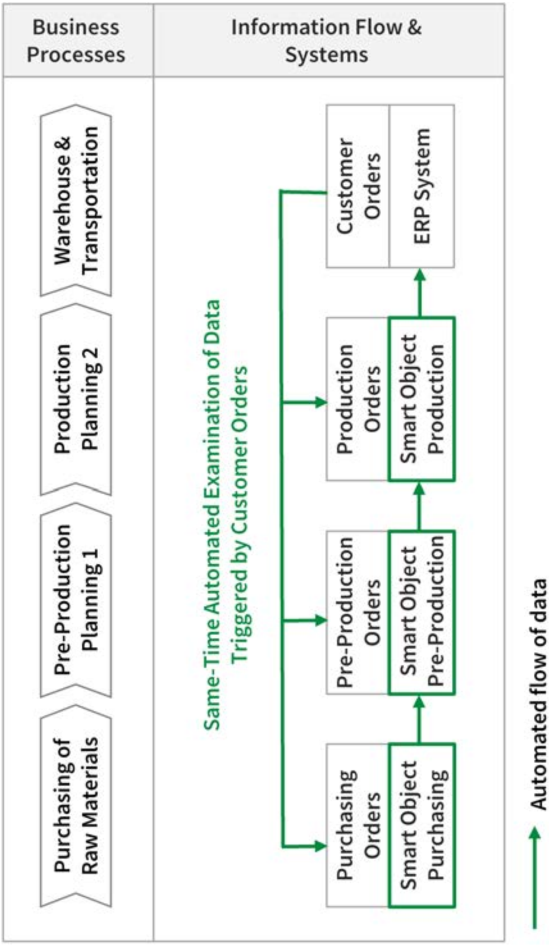

Figure 2: Adaptive Supply Chain

Which led to the target process, as shown in figure 2. In target process "Adaptive Supply Chain with Autonomous Information Flow" the customer orders are viewed as a trigger for the new calculation of production volume, which leads to the calculation of the pre-production volume, which as a result can cause new purchasing orders. Thus all departments will receive the data at the same time and the entire Supply Chain will be able to adapt itself to new customer orders within a short period of time.

The target architecture of systems and processes is not only intended to implement a new customized IT solution but also to change the information flow and as a result the entire method of working. It was agreed to define the target process based on the concept of Self-Organization/Autonomy with interconnected "Smart Objects" for autonomous data processing in each process group, such as Purchasing, Pre-Production, Production, as well as Warehouse & Transport as defined by Bischoff and ten Hompel (Agiplan GmbH, Fraunhofer IML and Zenit GmbH, 2015). In this way, they can independently analyze and share the data as well as take decisions on production and purchasing volumes. As a consequence, the people who work, for example, in purchasing department will be supported with data in near real-time mode, and employees in different departments will have same data at the same time.

4.3 Quality Requirements for Master Data

The self-organizing system can only exist if the master data is correct and the connection between single products, parts etc. is explicitly defined. For example, from the perspective of production planning of LED bulbs the end product of so-called twin-blister (2 products in 1 packaging) is the same product as "normal" bulb of the same type and can be produced in the same batch. For the packaging, warehouse and customer/consumer these are unequal products. If the twin-blisters should be sold from display instead of from regular shelves, they will be seen as different product type by the marketing department, even if they seem to be the same product for the customers and consumers. Consequently, the End-to-End communication strongly depends upon the ability to dissolve and reassemble the data generated by the needs of each process group or "Smart Object". Thus for the accurate information exchange throughout numerous departments master data should fulfill following requirements:

- All product variants such as differences in packaging for the co-equal product, products in marketing campaigns, packaging with different languages etc. should be differentiated in a system.
- All product components should be clearly identified in a system, regardless of their size.
- All bills of material and packing lists should be kept up-to-date.
- Explicit assignment of data – one product number should not be used for more than one type of product.

4.4 Implementation

Although the target architecture at a high-level was developed in one piece, the development and deployment of the software were separated into work packages according to the principles of the continuous deployment (Shahin, 2015):

- Small and independent deployment units.
- Considering operational aspects.
- Testability inside the architecture.

The operational focus in the architecture allowed the separation of the software solution into manageable independent units, starting with the operation next to the customer orders and moving toward the purchasing orders. Such an approach freed up the focusing on one task at a time, making the whole process transparent and manageable.

For example, the first task was to automate the decision in the production planning "should we produce the ordered volume or should we deliver the goods from the available stock?" At first sight, it is a very complex decision which involves many factors such as information about customers, seasonality for some products due to Christmas and other typical marketing promotions. There are many theories, on how to make an accurate decision as well as demonstrations of wrong decisions i.e. well-known Beer Distribution Game from Sterman (Sterman, 1989), which represents a tendency to accumulate unnecessary inventories called the Bullwhip effect (Forrester, 1968). Nevertheless, even under such complex circumstances, it is possible to automate the decision process and even improve the overall performance (Costas et al., 2017) using statistics and algorithms for the calculation of the safety stock.

Subsequently, the target process for the production planning was tested for one product group simultaneously to the “as is process”, which led to further improvements on the master data (s. Chapter 4.4). As a result, the production planning was performed ongoing in the background, starting the new calculation as soon as a new customer order which was higher than average planned volume entered the ERP system. In comparison to the old process, where the production planning was performed once per week one week upfront to the start of production, it drastically increased the reaction time of the whole supply chain and shortened the order-lead-time.

Other working packages were designed based on same logic as an example, making the whole process robust and transparent, saving time for the data analysis and decision-making.

In the first project the validation of the software was based on the Requirements Specifications which represented the target Architecture of IT-Systems on a detailed level. The requirements were documented and divided into mandatory and optional functions of the software. The validation of the second project solution was result-based: the automated flow of data improved the forecast accuracy by 13% five months in a row, which led to more precise purchasing volumes and as a consequence to lower level of stocks of finished goods and spare parts. The third project will be validated in 2017 based on a simulation of the business processes in a real-time mode simultaneously to the processes ”As Is”.

4.5 Risks and Benefits

Pressure to deliver high-quality value and deploy faster (Shahin, 2015) may cause a situation where sub-optimal solutions will be chosen over originally required systems, which would cause “architectural technical debt”, which is similar to a financial debt and has to be repaid in the long term (Vogel-Heuser et al., 2015). In our case, it would mean the risk of introducing a new solution which is incomplete, so that both old and new way of working would exist at the same time, causing high costs, low efficiency of a new system and most importantly, mistakes in relevant business decisions such as purchasing volume, production and the delivery of goods.

Despite the risks and high expenses of the implementation, the Adaptive Self-Organizing Supply Chain can produce multiple benefits, which can be divided into operational and strategic (Xue, 2014).

— Operational: lowering logistics costs, lowering operational costs, improving inventory control, increasing inventory turnover.

— Strategic: establishing a competitive advantage, improving customer relationships, improving supplier relationships.

In our use case, all the companies benefited from a shortening of order-lead-time by at least two weeks, which lead to lower level of inventory, not only for finished goods but also for spare parts and consequently, the costs for storage and handling. Thus, the benefits unquestionably outweighed the risks, which reduced the resistance towards changes within the company and accelerate the process of gaining acceptance.

5 Discussion

5.1 Contribution to Research and Practice

This study contributes to the topics of Self-Organizing Systems and Adaptive Supply Chains by providing a clear structured use case. The combination of real-time online data and increasing computer processing power has an immense impact on architecting new systems since it allows autonomous data collection and processing (Mortenson, Doherty and Robinson, 2015). In our use case, the automated data flow had a massive impact on the order-lead-time and accuracy of information.

However, as exemplified in the analysis of 52 research papers undertaken by Dikert (Dikert, Paasivaara and Lassenius, 2016) and a survey of almost 4,000 respondents executed by VersionOne Inc.(VersionOne Inc, 2016), the following barriers must be taken into consideration on the way to the implementation of projects:

— General organizational resistance. As stated in the ”Manifesto for Agile Software Development”, which came out in 2001 in USA (Fowler, Martin, Highsmith, Jim and Cockburn, Alistair, 2017), it is important that business people work together with the software development throughout the whole project in order to enforce the communication while lowering the resistance.

- Pre-existing rigid framework. Since the new software solutions will be implemented on a basis or with the co-existence with older software models, it is crucial to understand the evolution of predecessor models (Langer et al., 2013). Clearly defined requirements for the software allow for the technical implementation as well as the contractual relationship between the software providers and the process owners, which allow mitigating of the relevant project risks (Panunzio and Vardanega, 2014).

5.2 Limitations

The impact of the new system could be quantified only in terms of order-lead-time and accuracy of information. The impact on logistics and operational costs could not be precisely measured, due to complexity in the real-world environment:

- Change of sales volume at the end of various periods of time. Sales volume has a massive impact on costs per product since logistics costs are highly impacted by rent costs of the warehouse, costs of warehouse operator etc. Therefore it is hard to evaluate the exact impact of the new software implementation if the sales and product range were changed; even if the costs at the end of the reporting period were lower than before the rollout of the software.
- Other projects and marketing campaigns. Since the software project was not the only project in companies, it is impossible to separate the impact of one project on a company's performance (in all three cases the companies operate globally). A good example is the almost 40% reduction of so-called penalty costs (costs to B2B customers for not achieving service level agreements) after the roll-out of software. Although the software doubtless supported this achievement, it is still difficult to measure the exact level of influence, due to simultaneous application of a new system of financial reward for the employees by the management.

In order to investigate the potential for costs reduction due to the implementation of Self-Organizing Adaptive Supply Chain, the Business Innovation Lab at University of Applied Sciences in Hamburg will launch a research project, in which the influence of single parameters can be changed and evaluated on demand in controlled environments, based on the simulation of events.

A further limitation results in the difficulty of standardization of an IT-Solution for the development and implementation of a Self-Organizing Adaptive Supply Chain since every company has a specific business model and already has one or more customized IT-System with which new software will have interfaces. For this reason, it is important to have a methodological approach for evaluating the potentials and problems in each single case.

Due to the high complexity of software projects, the study is limited to the area of supply chain processes. However, the proposed approach can still be used for the development of an architecture for Self-Organizing Systems within other business areas such as marketing, R&D and sales.

6 Summary

The main task of the Supply Chain is to steer the processes throughout the different departments both inside and outside the company. This can only increase the performance of the entire company if the data collected by different participants and systems are interlinked with each other instead of the digitalization of the activities of only one department (Yuvaraj and Sangeetha, 2016; Coltman, Devinney and Midgley, 2011; Xue, Ray and Sambamurthy, 2013). It is also important to keep in mind, that an autonomous information flow does not mean 100% computer-based decisions. There is still some low percentage of errors or situations, where human interaction is required. However, even the partial implementation of the automated information flow makes the whole supply chain more robust and flexible to the changes in customer demand. The implementation of the self-organizing adaptive supply chain as a new and innovative business strategy supports companies by the extension of transparency of organization-wide processes. This in turn, enables data-based decision-making processes, which impact the market share and even help us to discover new strategic capabilities (Hazen et al., 2016). When supply chain activities achieve better results through the automation of decisions, it generates cost savings and improves the economic benefit for the company, shaping the supply chain into "the source of enterprises core competence" (Vogel-Heuser et al., 2015).

References

Agiplan GmbH and Fraunhofer IML and Zenit GmbH (2015). *Erschliessen der Potentiale der Anwendung von "Industrie 4.0" im Mittelstand*.

Bauernhansl, T., M. ten Hompel, and B. Vogel-Heuser, eds. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik*. de. DOI: 10.1007/978-3-658-04682-8. Wiesbaden: Springer Fachmedien Wiesbaden.

Bogaschewsky, R. and H. Müller (2016). *Industrie 4.0: Wie verändern sich die IT-Systeme im Einkauf und SCM?*

Coltman, T., T. M. Devinney, and D. F. Midgley (2011). "Customer relationship management and firm performance". In: *Journal of Information Technology* 26.3, pp. 205–219.

Costas, J., B. Ponte, D. de la Fuente, J. Lozano, and J. Parreño (2017). "Agents Playing the Beer Distribution Game: Solving the Dilemma Through the Drum-Buffer-Rope Methodology". In: *Engineering Systems and Networks*. Springer, pp. 337–345.

Dar, K., A. Taherkordi, H. Baraki, F. Eliassen, and K. Geihs (2015). "A resource oriented integration architecture for the Internet of Things: A business process perspective". en. In: *Pervasive and Mobile Computing* 20, pp. 145–159.

Dikert, K., M. Paasivaara, and C. Lassenius (2016). "Challenges and success factors for large-scale agile transformations: A systematic literature review". en. In: *Journal of Systems and Software* 119, pp. 87–108.

Dittrich, Y., K. Rönkkö, J. Eriksson, C. Hansson, and O. Lindeberg (2008). "Cooperative method development: Combining qualitative empirical research with method, technique and process improvement". en. In: *Empirical Software Engineering* 13.3, pp. 231–260.

Forrester, J. W. (1968). "Industrial dynamics—after the first decade". In: *Management Science* 14.7, pp. 398–415.

Gorschek, T., P. Garre, S. Larsson, and C. Wohlin (2006). "A model for technology transfer in practice". In: *IEEE software* 23.6, pp. 88–95.

Gunasekaran, A., M. Kumar Tiwari, R. Dubey, and S. Fosso Wamba (2016). "Big data and predictive analytics applications in supply chain management". en. In: *Computers & Industrial Engineering* 101, pp. 525–527.

Hazen, B. T., J. B. Skipper, J. D. Ezell, and C. A. Boone (2016). "Big data and predictive analytics for supply chain sustainability: A theory-driven research agenda". en. In: *Computers & Industrial Engineering* 101, pp. 592–598.

Herrmannsdoerfer, M. and M. Koegel (2010). "Towards a generic operation recorder for model evolution". In: *Proceedings of the 1st International Workshop on Model Comparison in Practice*. ACM, pp. 76–81.

Jones, D., S. Behrens, K. Jamieson, and E. Tansley (2004). "The rise and fall of a shadow system: Lessons for enterprise system implementation". In: *ACIS 2004 Proceedings*, p. 96.

Kassahun, A., R. Hartog, and B. Tekinerdogan (2016). "Realizing chain-wide transparency in meat supply chains based on global standards and a reference architecture". en. In: *Computers and Electronics in Agriculture* 123, pp. 275–291.

Kersten, W., T. Blecker, C. M. Ringle, and epubli GmbH, eds. (2015). *Sustainability in logistics and supply chain management: new designs and strategies*. eng. 1st ed. Proceedings of the Hamburg International Conference of Logistics (HICL) 21. OCLC: 933219309. Berlin: epubli GmbH.

Kumari, S., A. Singh, N. Mishra, and J. A. Garza-Reyes (2015). “A multi-agent architecture for outsourcing SMEs manufacturing supply chain”. en. In: *Robotics and Computer-Integrated Manufacturing* 36, pp. 36–44.
Langer, P., M. Wimmer, P. Brosch, M. Herrmannsdörfer, M. Seidl, K. Wieland, and G. Kappel (2013). “A posteriori operation detection in evolving software models”. en. In: *Journal of Systems and Software* 86.2, pp. 551–566.
Lippe, E. and N. Van Oosterom (1992). “Operation-based merging”. In: *ACM SIGSOFT Software Engineering Notes*. Vol. 17. ACM, pp. 78–87.
McKinsey Digital (2016). *Industry 4.0 after the initial hype. Where manufacturers are finding value and how they can best capture it*.
Mortenson, M. J., N. F. Doherty, and S. Robinson (2015). “Operational research from Taylorism to Terabytes: A research agenda for the analytics age”. en. In: *European Journal of Operational Research* 241.3, pp. 583–595.
O’Leary, D. E. (2008). “Supporting decisions in real-time enterprises: autonomic supply chain systems”. en. In: *Information Systems and e-Business Management* 6.3, pp. 239–255.
Panunzio, M. and T. Vardanega (2014). “A component-based process with separation of concerns for the development of embedded real-time software systems”. en. In: *Journal of Systems and Software* 96, pp. 105–121.
Perry, D. E., S. E. Sim, and S. M. Easterbrook (2004). “Case studies for software engineers”. In: *Software Engineering, 2004. ICSE 2004. Proceedings. 26th International Conference on*. IEEE, pp. 736–738.
Plattform Industrie 4.0 (2016). *Aspects of the research roadmap*.
Ponte, B., E. Sierra, D. de la Fuente, and J. Lozano (2017). “Exploring the interaction of inventory policies across the supply chain: An agent-based approach”. en. In: *Computers & Operations Research* 78, pp. 335–348.
Rentrop, C. and S. Zimmermann (2012). “Shadow IT”. In: *Management and Control of Unofficial IT. ICDS*, pp. 98–102.
Runeson, P. and M. Höst (2009). “Guidelines for conducting and reporting case study research in software engineering”. en. In: *Empirical Software Engineering* 14.2, pp. 131–164.
Shahin, M. (2015). “Architecting for DevOps and Continuous Deployment”. en. In: ACM Press, pp. 147–148.
Sterman, J. (1989). *Modelling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment.*
VersionOne Inc (2016). *10th Annual State of Agile Report.*
Vogel-Heuser, B., A. Fay, I. Schaefer, and M. Tichy (2015). “Evolution of software in automated production systems: Challenges and research directions”. en. In: *Journal of Systems and Software* 110, pp. 54–84.
Voß, P. H., ed. (2015). *Logistik – eine Industrie, die (sich) bewegt*. de. DOI: 10.1007/978-3-658-10609-6. Wiesbaden: Springer Fachmedien Wiesbaden.
Waterman, M. G. (2014). “Reconciling agility and architecture: a theory of agile architecture”. In:
Wellbrock, W. (2015). *Innovative Supply-Chain-Management-Konzepte*. de. DOI: 10.1007/978-3-658-09181-1. Wiesbaden: Springer Fachmedien Wiesbaden.
Xue, L. (2014). “Governance–knowledge fit and strategic risk taking in supply chain digitization”. en. In: *Decision Support Systems* 62, pp. 54–65.
Xue, L., G. Ray, and V. Sambamurthy (2013). “The impact of supply-side electronic integration on customer service performance”. en. In: *Journal of Operations Management* 31.6, pp. 363–375.

Supply Chain Process Oriented Technology-Framework for Industry 4.0

Florian Schlüter[1], Endric Hetterscheid[1]

1 – Technical University of Dortmund

Digitalization in supply chains is an arising topic. Screening recent publications in this field delivers no application-oriented classification of potential Industry 4.0 technologies for supply chain processes. The purpose of this paper is to present an application-oriented Technology-Framework speeding up the development of digitalization scenarios for supply chain processes.A structured literature review will be carried out to identify and extract relevant technologies within the field of Industry 4.0. Afterwards, the Process Chain Model will be used to come up with standardized and application-oriented categories for technologies to derive a framework. Based on a comparative study, the Process Chain Model was especially developed for illustrating and transforming supply chain and logistics processes.The new Technology-Framework supports the transformation process by giving the user (1) a standardized framework for technology categorization and (2) by giving a comprehensive overview about existing technologies in the literature. The framework serves as a basis for future supply chain process transformation. By grouping the technologies around approved categories – originally defined for describing process chain elements – it speeds up the identification and selection of appropriate technologies.

Keywords: Industry 4.0; Supply Chain Management; Digitalization; Technology scouting

1 Introduction

Digitalization plays an important role in many sections of daily life. In the industrial environment, more and more companies are also pursuing measures to integrate technologies into business processes and thus to digitize their processes (Roth, 2016b). In the literature exist further terms with a similar meaning for digitalization (Hermann, Pentek and Otto, 2016). Especially the term of Industry 4.0 (I4.0) has determined both the economy and science for some years (Wan, Cai and Zhou, 2014). Background of the terminology is the increasing customer requirements for individualized products. The resulting smaller batch numbers down till batch size one and shorter product life cycles lead to steadily growing challenges not only for production and logistics, but throughout the entire supply chain (SC) (Bauernhansl, 2014). In order to counteract this increasing complexity and to meet the market requirements with regard to price, quality and time, companies are forced to increase their technological standard in their SC processes (Kersten, et al., 2016). Thereby I4.0 pledges improvement in flexibility, product quality, delivery time and deliverability in value-added networks (Bauernhansl, 2014).

The term of I4.0 is described by the use of existing technologies, such as microcomputers, broadband internet access, radio frequency identification (RFID), and stronger networking creating a comprehensive transparency and processing of information along the entire value chain (Siepmann, 2016a). Additionally, I4.0 is also to be seen as a new optimization approach, because a faster information flow results from a reduction in media discontinuities and a stronger technological and organizational process transparency. As a result, more tightly clocked process chains emerge (Schlick, et al., 2014).

Although the term of I4.0 has been in existence for several years, there is still no uniform definition (Siepmann, 2016b). For this paper, the holistic definition of Roth (2016b) will be used. He defines I4.0 as ”[...] the networking of all human and machine actors over the entire value chain as well as the digitalization and real-time evaluation of all relevant information with the aim of making the processes of value creation more transparent and efficient in order to use intelligent products and services to optimize customer use”.

The “Dortmund Management-Model for Industry 4.0” by Henke gives a further direction for practitioners and researchers with establishing and formalizing “work-clusters” in a two-dimensional matrix for transforming value creating activities (ten Hompel and Henke, 2017). The first dimension describes a company perspective with ”Technology”, ”Organization” and ”Process” as characteristics. The second dimension has a management perspective with "normative Level", "Planning", "Implementation" and "Monitoring" as characteristics. The following paper contributes to the work-cluster of "Technology scouting" within the "Technology" and "Planning" dimensions.

In this context, science is discussing the extent to which a revolution can be addressed in I4.0. Accordingly to Dais (2014), there are two different groups regarding interpretation of the term. One group recognizes I4.0 as revolutionary as it brings innovative improvements with it that have not yet existed. The other group speaks of evolution, since the technologies are "nothing new", but constantly evolving and improving.

Despite this fact, I4.0 technologies can make a valuable contribution to the digitalization and autonomization of processes. However, not many efforts beyond I4.0 pilot projects are carried out in practice. Oftentimes, I4.0 technologies are implemented only partially in the logistics or production, so that the desired cost and benefit effect for companies does not occur (Graef, 2016). The reason for partial solutions is often insufficient knowledge about the correct use of the right technology for the respective process. Meanwhile, a large number of technological solutions exist to improve business processes (Kersten, et al., 2016) and a support is required to help companies in the correct use of I4.0 technologies in existing SC processes.

In recent literature, I4.0 technologies and fields, illustrated with mind maps and other classification methods, are known (Pfohl, Yahsi and Kurnaz, 2015; Kersten, et al., 2016). However, these classifications are not very suitable for practice. Also I4.0 technologies are described in use cases in which these technologies are often used only in production or logistics and not in the overall context of a SC (e.g. Zhang, et al., 2014). In addition, there is no framework in the literature that provides the technologies of I4.0 for the optimization of SCs. Therefore, the aim of this paper is to develop a Technology-Framework that provides methodological support for the optimization of SC processes. For this purpose, the following research questions (RQs) arise:

RQ 1: Which existing technologies in the literature relate to the context of I4.0 and how can they be classified for practical usage?

RQ 2: How can a relation between the identified technologies and classical process optimization methods be established?

In order to answer these RQs, the methodological approach will be explained in section 2. In section 3, the methodology will be executed and an overview of the existing literature in the research field will be provided. The development of the Technology-Framework by listing existing I4.0 technologies, establishing a relation between them and process optimization as well as integrating the results into the optimization framework will take place in section 4. In section 5, a conclusion and further needs for research follow.

2 Methodology

Today, the whole topic of I4.0 is still an emerging, under-developed and highly diverse research field (Pfohl, Yahsi and Kurnaz, 2015; Glas and Kleemann, 2016) and the application of more exploratory research methods is suitable to give first directions (Stebbins, 2001) instead of a final answer. Three principal ways of conducting exploratory research are mentioned in the literature (Saunders, Lewis and Thornhill, 2009): Search of the literature; Interviewing experts in the subject; and Conducting focus group interviews.

At first a structured literature review (SLR) based on an adopted approach for systematic literature review from Denyer and Tranfield (2009) has been performed, to answer the preceded RQs. Reviews that are evidence-based like SLRs allow for a higher objectivity of the search results while eliminating error or bias issues (Kilubi and Haasis, 2016). Denyer and Tranfield (2009) defined the following stages: (1) Question formulation; (2) Locating studies; (3) Study selection and evaluation; (4) Analysis and synthesis; and (5) Reporting and using the results – a more detailed description can be found in the literature. For each of those stages the authors proposed more detailed steps to fulfill each stage. The whole methodology is summarized in Figure 1.

Stage (1) has already been completed with formulating the RQs in section 1. Stage (2) and (3) follow in the next section (see section 3). There existing literature will be located and selected based on criteria. The section ends with an overview about existing publications which will be used for stage (4) (see section 4). In stage (4) the selected literature will be screened for relevant technologies and the Technology-Framework will be developed based on the findings and supported through group discussions (see section 4).

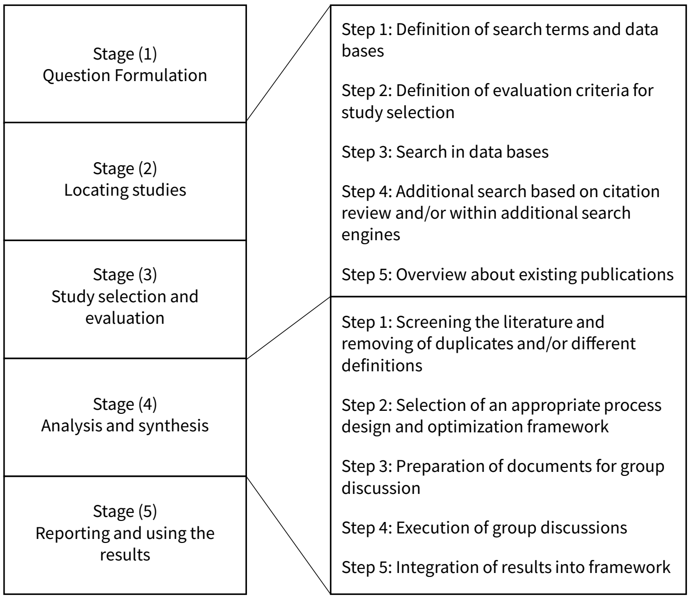

Figure 1: Proposed methodology

3 Research Overview based on located and selected studies

Step 1: Definition of search terms and data bases

During a brainstorming session the key words “Industrie 4.0” and “Industry 4.0” have been selected. The authors chose these words to gather as much literature as possible for collecting mentioned technologies. Both terms are usually connected through an ”OR” operand for the search engines – this leads to results when at least one of the terms is included in the title, abstract or key words. The actual way of keyword combination depended on the used search engine, thus test searches took place to identify the correct way of formulation.

The SLR uses a broad range of databases based on screening existing literature reviews like (Ho, et al., 2015; Kilubi and Haasis, 2016). The following databases have been identified as suitable: IEEExplore, Science Direct, Springer, Emerald, EBSCOhost and Taylor and Francis. Also the publications should be in English or German.

Step 2: Definition of evaluation criteria for study selection

The search in databases and study selection took place in April 2017 and is based on three evaluation criteria, related to the research questions:

Criterion 1: Cluster and/or lists of technologies in the context of I4.0

Criterion 2: Description of a use case in the context of I4.0

Criterion 3: Description of a methodological SC process optimization based on technologies in the context of I4.0

Criterion 1 and 2 have been chosen because technologies in the context of I4.0 are often mentioned within lists or specific use cases. The third criterion has been chosen to include existing literature possibly covering the second RQ.

Table 1: Overview of search results

Database	Results	1. Check	2. Check
EBSCOhost	69	15	0
Emerald	15	4	0
IEEExplore	319	49	2
ScienceDirect	573	66	0
Springer	1.963	123	7
Taylor & Francis	44	11	0
Sum	2.983	268	9

Step 3: Search in data bases

During the search process, a publication has to fulfill at least one of the mentioned criteria when checking the abstracts or in case of a book the introduction and index. Afterwards the remaining literature has been screened in more detail based on the aforementioned criteria. The number of publications in scientific databases can be seen in the following table (see Table 1).

As mentioned above the topic of I4.0 is still an emerging research field (Pfohl, Yahsi and Kurnaz, 2015; Glas and Kleemann, 2016). Which results in only a very limited number of classified research publications with relation to I4.0 and the formulated RQs. Publications about I4.0 can mostly be found in scientific magazines and lower-rated journals or they are studies published by companies or research institutes (Pfohl, Yahsi and Kurnaz, 2015). That's why an additional semi-structured literature search is necessary.

Step 4: Additional search

Because Google Scholar is more complete than other databases (Kilubi and Haasis, 2016), and covers also scientific magazines, lower-rated journals as well as studies it has been used additionally.

Step 5: Overview about existing publications

Applying the aforementioned selection criteria brings additional 23 publications leading to 32 in total. The 32 publications are evaluated in the Table 2 below.

As it can be seen in Table 2, most of the published literature describes potentials of certain technologies in the context of I4.0 or a use case where technologies are already applied in industry. In the third column, a paper is marked if it describes the link between I4.0 technologies and SC processes. Few are marked and all of them fulfill this condition only partly. The reason is that they are describing mainly the potentials of I4.0 technologies in SC processes (Rozados and Tjahjono, 2014; Pfohl, Yahsi and Kurnaz, 2015; Schrauf and Berttram, 2016). None of the identified literature describes a methodological approach which links a SC optimization framework with I4.0 technologies giving guidelines during the SC optimization process.

Table 2: Overview and evaluation of publications

Source	Listing of Technologies	Use case related	Methodological link to SC process (optimization)
Bauer, et al. (2014)	×	×	(×)
Bauernhansl, et al. (2016)	×	×	
Bartodziej (2017)	×		
Bechtold, et al. (2014)	×		(×)
Bauernhansl (2014)	×		
Bienzeisler, Schletz and Gahle (2014)	×		
Bischoff (2015)	×	×	
Bloching, et al. (2015)	×		
Gausemeier, et al. (2016)	×		
Geissbauer, Vedso and Schrauf (2016)	×		
Hausladen (2016)	×		
Hermann, Pentek and Otto (2016)	×		
Horvath & Partners (2017)	×		
Huber (2016)	×	×	
Jäger, et al. (2015)	×		
Kersten, et al. (2017)	×	×	
Obermaier (2016)	×		
Pfohl, Yahsi and Kurnaz (2015)	×		(×)
Plattform Industrie 4.0 (2015)	×		
Roth (2016a)	×	×	
Rozados and Tjahjono (2014)	×	×	(×)
Rüßmann, et al. (2015)	×	×	
Schlaepfer, Koch and Merkofer (2015)	×		
Schrauf and Berttram (2016)	×		(×)
Schwab (2016)	×		
Seiter, et al. (2016)	×	×	
Siepmann (2016b)	×	×	
Wee, et al. (2015)	×		
Wehberg (2015)	×		
Wischmann, Wangler and Botthof (2015)	×		
Wollschlaeger, Sauter and Jasperneite (2017)	×		
Zillmann and Appel (2016)	×	×	(×)

× = Fully fulfilled; (×) = Partly fulfilled

4 Study analysis and synthesis for framework development

After study selection and thus completing step 2 and 3 of the proposed methodology (see section 3 and figure 1) the aim of this section is to identify and select technologies within the field of I4.0 through literature screening and to develop a usable framework, in accordance with step 4 of the proposed methodology (see figure 1).

Step 1: Screening the literature and removing of duplicates/and or different definitions

By screening the literature, 124 artifacts related to I4.0 could be identified which can be interpreted as I4.0 technology. The artifacts will be divided between technologies and I4.0 concepts. Due to the missing definition of I4.0 technology the authors decided to define such a technology as "directly recognizable entity and real existing physical hardware or logical software which is financially activatable and supports or realizes the principles and ideas of I4.0". The next step was to remove duplicate and/or different definitions with the same meaning (see Figure 1). Also similar technologies have been clustered to technology fields to make the later combination with the process optimization framework easier. As a result, the number of technological artifacts could be reduced to 45. Based on that definition, the authors could divide the artifacts as described in the list below (see Table 3).

The concepts are more overarching and abstract ideas or principles which become real by using the technologies (e.g. by using Cyber-Physical-Systems and analytics a predictive maintenance can be realized; using smart devices together with other devices over the internet creates the Internet-of-Things) while the technologies are more tangible through certain hardware, software or objects. Only the technologies on the left side have been used for the later framework. This list also answers the first RQ.

Table 3: I4.0 Artifacts classified in Technology and Concept

Technology	Concept
3D-Printing	Augmented Reality
Actuators	Automation
Analytics	Cloud Computing
Apps	Gamification
Artificial Intelligence (Software)	Horizontal Integration
Autonomous Transport Vehicles	Internet of Things and Services
Big Data	IT-Security
Blockchain	Machine to Machine Communication
Business Management Software/Systems (e.g. ERP, APS)	Predictive Maintenance
CAx (e.g. CAD, CAM)	Smart Factory
Cyber-Physical-System	Smart Grids
Data glasses/Head-Mounted Display	Smart Logistics
Data Mining	Ubiquitous Computing
Digital Shadow	Vertical Integration
Embedded Systems	Virtual Reality
Human Machine Interaction (e.g. Touch interfaces)	
Identifiers (e.g. Barcodes, RFID, QR-Code)	
Image Recognition	
Internet Protocol (e.g. IPv6)	
Mobile Communication (Infrastructure)	
Mobile Devices (e.g. Smart phone, tablet)	
Pick-by-Technology	
Real-time Data	
Robotics	
Sensors	
Simulation	
Smart Objects/Products	
Smart Payment (Software)	
Social Media	
Wearables (e.g. Data glasses, Head mounted displays)	
Wireless Communication (Infrastructure)	
Sum: 30	Sum: 15

Step 2: Selection of an appropriate process design and optimization framework

Due to the focus on SC processes an appropriate process design framework comes from Kuhn (1995). Based on a comparative study only the Process Chain Model of Kuhn (1995) was especially developed for logistic and SC processes (Nyhuis and Wiendahl, 2009) and is part of the Process Chain Instrument. The Process Chain Model enables a holistic visualization and analysis of performance object flows. Deficiencies in the processes can be clarified across hierarchy levels. Another advantage is the strong integration of the employees into process optimization. The process chain representation can be used as a communication medium, since it is a form which is understandable to all, irrespective of the organizational structure. This greatly promotes the acceptance of process changes. During optimization, processes are presented with the design elements system load (sources and sinks), process flow, steering, structures and resources (Kuhn, 2008).

Sources and sinks form the interfaces between the system and the process chain to its environment. Through the sources, performance objects enter the system and leave it transformed over the sink. The entirety of all performance objects that influence a process is called a system load. The process flow can be subdivided into subordinate processes and these can be further detailed as required. Together with the source and sink, they represent the process structure. The process chain elements are subject to various rules and steering rules, e.g. the decision-making scope of neighboring processes. This is referred as steering and is divided into five different steering levels. For the transformation of the performance objects, resources are claimed in the process. The steering levels are responsible for minimizing resource costs through efficient use in the process. The structures describe the classification of process chain elements into a company. These design elements of a process are divided into 17 different potential classes. With the help of the potential classes, processes can be precisely described and investigated for improvement potentials. Through this type of a ”checklist” action alternatives with their respective effects in the process optimization can be opened up (Kuhn, 2008). These 17 potential classes will be explained below (subsequent (Kuhn and Hellingrath, 2002).

Process

Source: Sources are the inputs into a process chain element. They define the input side system load and thus they represent an interface part between the process chain element and the environment. Sources describe the performance objects that must be transformed by the process per time unit.

Sink: Sinks represent the counterpart to sources. They describe which performance objects (information or material) are transformed to the following process chain elements. At the sink, the object triggers a retrieval behavior of the subsequent process.

Process structure: A process chain element represents the process structure with the sources and sinks. The process types are processed/checked, transported, stored or buffered. The process structure can be modified as part of an optimization with the following process chain modulation: Grouping, parallelizing, extending, shortening, eliminating or exchanging processes.

Resource

Personnel: This includes all employees who are available in a process during the operating time. On the one hand, the employee is described in terms of his training, qualification and motivation. On the other hand, the work organization and the flexibility of working and break times are described. These parameters significantly influence the performance of a process.

Area: The resource ”area” is used to list all the operational areas for the transformation of the basic object in a process. It has an impact on investment and operating costs. Small areas lead to an extension of process times or to the limitation of action options.

Stock: The stock comprises the number of basic objects in a process. A distinction is made between materials (e.g. raw materials) and the number of customer or production orders. Stocks are an important control lever in logistics because they have a significant impact on a variety of logistical key figures.

Tools and Machinery: This includes all resources that are responsible for the direct transformation of the object. Typical tools and machinery are production machines and systems or conveyor and storage systems. In a logistical process, transports which carries out the transfer of the object from a source to a sink can also be assigned to this category.

Working aids: This category is assigned to all the resources that are required for the transformation of objects in supportive form. These are e.g. loading aids such as cranes. Particularly in external logistics is the selection of working tools significant.

Organizational means: Organizational means are used to summarize all the resources required for information processing in a process. These include information carriers (e.g. bar codes), information storage, computer architectures, and software programs.

Structure

Layout: The layout, which is often referred to as a topology, determines the arrangement of the work equipment as well as the area and determines the transport links. Thus, the layout significantly influences area usage. In an optimal layout, envelope processes are tried to avoid.

Organizational structure: In this case, the process responsibility is determined within a process chain element. This includes communication and decision-making structures and thus has a significant influence on the ways of information and material flow within the process structure. The goal is to share information more quickly and make resources more flexible to use.

Technical communication structure: This category includes the technical networking of all implemented external and internal systems. These are IT and EDV structures, which are necessary for processing.

Steering levels

Normative: In this category, a company's superordinate values, objectives and standards with reference to a process chain element are described. Thereby, the change of the process is specified. All other potential classes must be able to measure and evaluate these requirements.

Administrative: This level has the task of coordinating the system load with the upstream and downstream process chain elements and assessing future loads. It collects orders based on the sources and sinks and remit them to the normative level. The administrative level also defines current targets, which are aligned with the requirements of the normative level.

Dispositive: This level aims to analyze the system load of the administrative level under existing boundary conditions and optimization criteria. The results are provided to the network level. The orders are assigned to resources and the sequencing of orders is carried out.

Network: The network level coordinates and synchronizes several related processes using autonomous rules to meet customer requirements. The order assignment of the dispositive level is taken over and executed according to the appropriate rules. The difference between the network levels at the administrative level is that the optimized assignment of requests to resources is not taking place, but rather the autonomous rules for the flexible use of interchangeable resources.

Control: The control level has the task of executing the specifications from the network level for a single performance object in a sub-process. The control system performs simple decision rules. At this level, the targets are measured and compared with the relevant agreements.

After selecting an appropriate framework for SC optimization and collecting the relevant I4.0 technologies, the next step is to connect both aspects methodologically. This happens in the next step with the help of group discussions.

Step 3: Preparation of documents for group discussion

For assigning I4.0 technologies to the process design framework the authors chose focus group discussions as an appropriate method. Those focus group interviews capitalize on communication between research participants to generate data (Kitzinger, 1995). This method is useful for exploring people's knowledge and experiences (Kitzinger, 1995). Two documents were created for the focus group discussions. The first document contained the aforementioned technologies and potential classes. Participants should mark for each technology where they see a direct impact on which potential class. The second document was prepared for the second discussion round in which the results were clustered based on the potential classes and participants had to select whether or not they agree on the technology assignment. In case they disagree they also should mention why, as well as when they think a technology is relevant but was not assigned in the first round.

Step 4: Execution of group discussions

Two group discussion rounds took place. At first four experts for topics of digitalization and I4.0 were selected, who are employees at a research institute. The I4.0 technologies and potential classes were briefly explained by a moderator. The objectives of the survey was named, in which the experts should assign the technologies to the various potential classes. The experts should consider which technical key feature of a particular technology could yield the greatest benefit for a potential class with focus on the material flow. It has to be noted that the Process Chain Model was originally designed to model material, information and financial flows within SCs and depending on the kind of flow the meaning of the potential class could change thus the relevance of a technology for a potential class could also change and makes the assignment harder. It was allowed to assign an I4.0 technology to several potential classes. The experts received an overview of the technologies and different potential classes. They were given the opportunity to talk about the task and to communicate their respective opinions. The results were evaluated by the moderator and the discrepancy in the results were presented and discussed. Afterwards, a second focus group discussion took place, consisting of eight participants from research. The participants were different from those in the first round and their knowledge about I4.0 technologies differed. This led to more discussions and created more group dynamic. Finally, the documents were collected by the moderators, evaluated and the improved results were used to form the following Technology-Framework.

Step 5: Integration of results into framework

The following framework is the result of a structured literature review and two rounds of focus group discussions. From 17 potential classes 15 were used to assign technologies. The potential classes ”Normative” and ”Layout” have not been selected by the participants thus they were neglected from the framework. The proposed Technology-Framework answers the last RQ and can now be used within process optimization activities as a supportive tool to stimulate the creativity of the participants (see figure 2 - figure 3). It has to be noted that there may be

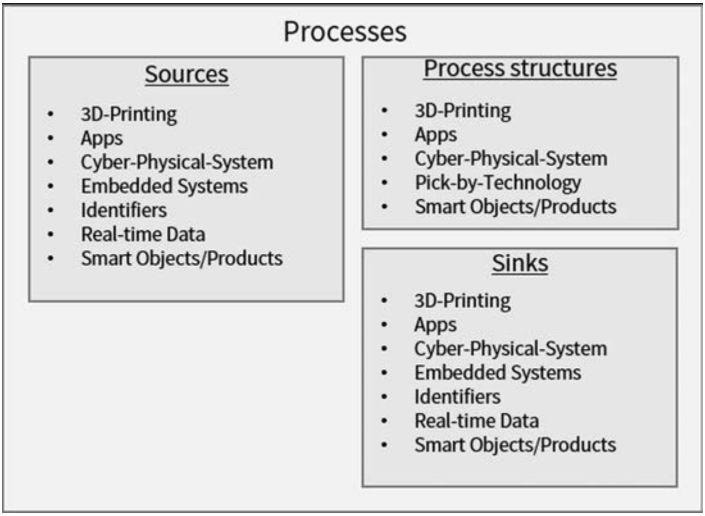

Figure 2: Technology-Framework (1/4) – Processes

cases where some technologies are not applicable in their particular potential class or where additional technologies are suitable.

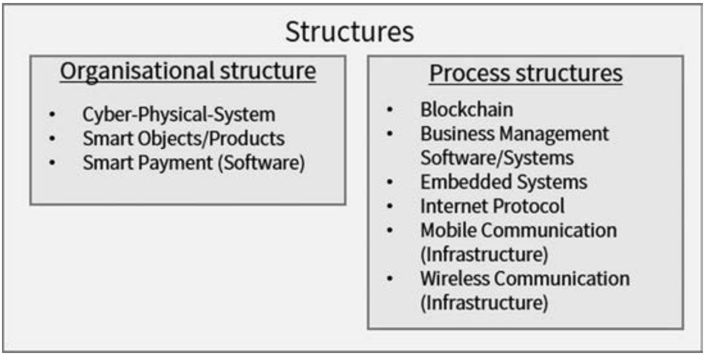

Figure 3: Technology-Framework (2/4) – Structures

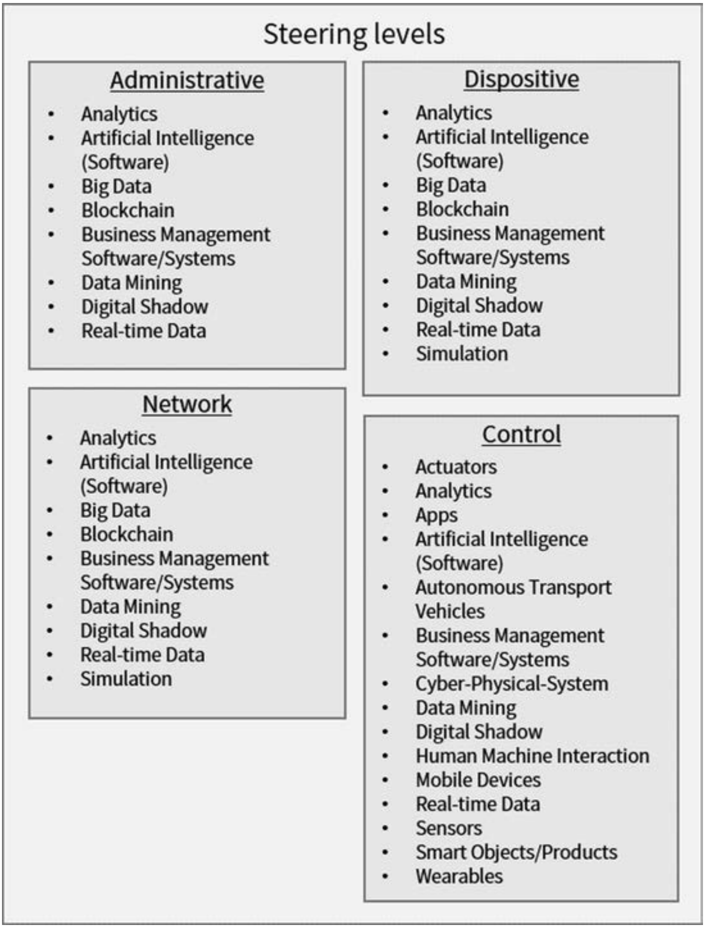

Figure 4: Technology-Framework (3/4) – Steering levels

Resources

Personnel

- Apps
- CAx
- Human Machine Interaction
- Mobile Devices
- Pick-by-Technology
- Real-time Data
- Social Media
- Wearables

Working aids

- 3D-Printing
- Actuators
- Autonomous Transport Vehicles
- Cyber-Physical-System
- Embedded Systems
- Human Machine Interaction
- Identifiers
- Image Recognition
- Pick-by-Technology
- Real-time Data
- Robotics
- Sensors
- Smart Objects/Products
- Wearables

Areas

- Actuators
- Cyber-Physical-System
- Embedded Systems
- Sensors
- Smart Objects/Products

Tools and Machines

- 3D-Printing
- Actuators
- Autonomous Transport Vehicles
- Cyber-Physical-System
- Embedded Systems
- Human Machine Interaction
- Identifiers
- Real-time Data
- Robotics
- Sensors
- Smart Objects/Products

Organisational means

- 3D-Printing
- Actuators
- Autonomous Transport Vehicles
- Cyber-Physical-System
- Embedded Systems
- Human Machine Interaction
- Identifiers
- Image Recognition
- Pick-by-Technology
- Real-time Data
- Robotics
- Sensors
- Smart Objects/Products
- Wearables

Stocks

- Cyber-Physical-System
- Identifiers
- Smart Objects/Products

Figure 5: Technology-Framework (4/4) – Resources

5 Conclusion and Further Research

The paper presents a first approach of linking I4.0 technologies with specific elements of a SC optimization framework based on exploratory research methods. The purpose is to guide practitioners during optimization activities by generally giving an overview about technological options they have and also – by locating improvement potential within the elements of a SC optimization framework – giving an overview on which technologies suite best for certain problems. Linking technologies with certain process characteristics makes it also easier to evaluate the benefits because it is easier to select appropriate process KPIs for measurement. The technologies are methodologically collected from the literature with a structured literature review (see section 2 and 3) and the link to the SC optimization elements has been created with focus group discussions (see section 4).

5.1 Limitations and further research

There is only limited high-ranked literature about I4.0 and regarding technologies available. Due to that the authors mainly used non-scientific publications for the review. The authors also focused only on technologies within the context of I4.0 which may limit the presented technology selection. Also the categorization depends highly on the qualification and number of experts included in focus groups. The selected experts are mainly experienced researchers and very familiar with I4.0 technologies as well as with the Process Chain Model. One way to improve the proposed framework could be to set-up a broad survey or workshops with practitioners and to assign technologies not only for the material but also for the information and financial flow. To give direction within SC optimization activities, the Process Chain Model and its elements have been used due to its focus on logistic and SC processes. The suitability of other frameworks like Event-driven Process Chain (EPC) or Supply Chain Operation Reference-Models (SCOR) should be tested in further research. After creating a valid Technology-Framework, it should be applied in practice.

However, the framework serves as a basis for future SC process transformation. By grouping the technologies around approved categories – originally defined for describing process chain elements – it speeds up the identification and selection of appropriate technologies. The framework is especially designed for practitioners to speed up future transformation processes towards a digitalized SC.

References

Arnold, D., A. Kuhn, K. Furmans, H. Isermann, and H. Tempelmeier, eds. (2008). *Handbuch Logistik*. 3., neu bearbeitete Aufl. VDI-Buch. Berlin: Springer.

Bartodziej, C. J. (2017). *The Concept Industry 4.0: An Empirical Analysis of Technologies and Applications in Production Logistics*. Wiesbaden: Springer Gabler.

Bauer, W., S. Schlund, D. Marrenbach, and O. Ganschar (2014). *Industrie 4.0 - Volkswirtschaftliches Potenzial für Deutschland*. Ed. by BITKOM and Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO.

Bauernhansl, T. (2014). "Die Vierte Industrielle Revolution – Der Weg in ein wertschaffendes Produktionsparadigma". In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by T. Bauernhansl, M. ten Hompel, and B. Vogel-Heuser. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 5–35.

Bauernhansl, T., M. ten Hompel, and B. Vogel-Heuser, eds. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Wiesbaden: Springer Fachmedien Wiesbaden.

Bauernhansl, T., J. Krüger, G. Reinhart, and G. Schuh (2016). *WGP-Standpunkt Industrie 4.0*. Ed. by Wissenschaftliche Gesellschaft für Produktionstechnik WGP e.V. Darmstadt.

Bechtold, J., A. Kern, C. Lauenstein, and L. Bernhofer (2014). *Industrie 4.0 - EIne Einschätzung von Capgemini Consulting: Der Blick über den Hype hinaus*. Ed. by Capgemini Consulting.

Bienzeisler, B., A. Schletz, and A.-K. Gahle (2014). *Industrie 4.0 Ready Services Technologietrends 2020: Ergebnisse einer Kurzbefragung auf der Messe MAINTAIN 2014*. Ed. by Fraunhofer-Institut für Arbeitswissenschaft und Organisation IAO. Stuttgart.

Bischoff, J. (2015). *Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand*. Ed. by agiplan GmbH 2015.

Bloching, B., P. Leutiger, T. Oltmanns, C. Rossbach, T. Schlick, G. Remane, P. Quick, and O. Shafranyuk (2015). *Die digitale Transformation der Industrie: Was sie bedeutet. Wer gewinnt. Was jetzt zu tun ist*. Ed. by Roland Berger Strategy Consultants GmbH and Bundesverband der Deutschen Industrie e.V.

Buchanan, D. and A. Bryman, eds. (2009). *The Sage Handbook of Organizational Research Methods*. London: Sage Publications.

Bui, T. X. and R. H. Sprague, eds. (2016). *Proceedings of the 49th Annual Hawaii International Conference on System Sciences: 5-8 January 2016, Kauai, Hawaii*. Piscataway, NJ: IEEE.

Dais, S. (2014). "Industrie 4.0 – Anstoß, Vision, Vorgehen". In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by T. Bauernhansl, M. ten Hompel, and B. Vogel-Heuser. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 625–634.

Denyer, D. and D. Tranfield (2009). "Producing a Systematic Review". In: *The Sage Handbook of Organizational Research Methods*. Ed. by D. Buchanan and A. Bryman. London: Sage Publications, pp. 671–689.

Gausemeier, J., R. Dumitrescu, J. Jasperneite, A. Kühn, and H. Trsek (2016). *Auf dem Weg zu Industrie 4.0: Lösungen aus dem Spitzencluster it's OWL*. Ed. by it's OWL Clustermanagement GmbH. Paderborn.

Geissbauer, R., J. Vedso, and S. Schrauf (2016). *Industry 4.0: Building the digital enterprise*. Ed. by PwC.

Glas, A. H. and F. C. Kleemann (2016). "The Impact of Industry 4.0 on Procurement and Supply Management: A Conceptual and Qualitative Analysis". In: *International Journal of Business and Management Invention* 5.6, pp. 55–66.

Graef, N. (2016). "Industrie 4.0-Gesamtkonzept: Zusammenspiel von intelligenten Infrastrukturen, Paradigmen und technologischen Komponenten". In: *Einführung und umsetzung von Industrie 4.0*. Ed. by A. Roth. Gabler, pp. 73–82.

Hans-Christian, P., Y. Burak, and K. Tamer (2015). "The Impact of Industry 4.0 on the Supply Chain". In: *Innovations and Strategies for Logistics and Supply Chains*. Ed. by W. Kersten, T. Blecker, and C. M. Ringle. Vol. 20. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin: epubli GmbH, pp. 31–58.

Hausladen, I. (2016). *IT-gestützte Logistik: Systeme - Prozesse - Anwendungen*. 3. Aufl. 2016.

Hermann, M., T. Pentek, and B. Otto (2016). "Design Principles for Industrie 4.0 Scenarios". In: *Proceedings of the 49th Annual Hawaii International Conference on System Sciences*. Ed. by T. X. Bui and R. H. Sprague. Piscataway, NJ: IEEE, pp. 3928–3937.

Ho, W., T. Zheng, H. Yildiz, and S. Talluri (2015). "Supply chain risk management: a literature review". In: *International Journal of Production Research* 53.16, pp. 5031–5069.

Horvath & Partners (2017). *Technologische Trends in der Industrie 4.0*. Ed. by Horvath & Partners.

Huber, W. (2016). *Industrie 4.0 in der Automobilproduktion: Ein Praxisbuch*. Wiesbaden: Springer Viehweg.

Industrie 4.0 - Whitepaper FuE-Themen (2015). http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Aktuelles___Presse/Presseinfos___News/ab_2014/Whitepaper_Industrie_4.0.pdf.

Jäger, J. M., D. Görzig, D. Paulus-Rohmer, H. Schatton, S. Baku, M. Weskamp, and D. Lucke (2015). *Industrie 4.0 - Chancen und Perspektiven für Unternehmen der Metropolregion Rhein-Neckar*. Ed. by Industrie- und Handelskammern Rhein-Neckar, Pfalz und Darmstadt Rhein Main Neckar.

Kersten, W., T. Blecker, and C. M. Ringle, eds. (2015). *Innovations and Strategies for Logistics and Supply Chains: Technologies, Business Models and Risk Management*. 1st ed. Vol. 20. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin: epubli GmbH.

Kersten, W., M. Seiter, B. von See, N. Hackius, and T. Maurer (2017). *Trends und Strategien in Logistik und Supply Chain Management: Chancen der digitalen Transformation*. Ed. by Bundesvereinigung Logistik. Bremen.

Kersten, W., M. Seiter, B. von See, N. Hackius, C. Rosentritt, C. Böhle, G. Reich, T. Maurer, and R. Sauter (2016). "Trends und Strategien in Supply Chain Management und Logistik - Chancen der digitalen Transformation". In: *Den Wandel gestalten*. Ed. by T. Wimmer and C. Grotemeier. Schriftenreihe Wirtschaft & Logistik. Hamburg: DVV Media Group GmbH, pp. 344–361.

Kilubi, I. and H. D. Haasis (2016). "Supply chain risk management research: Avenues for further studies". In: *International Journal of Supply Chain and Operations Resilience* 2.1, p. 51.

Kitzinger, J. (1995). "Introducing focus groups". In: *BMJ* 311, pp. 299–302.

Kuhn, A. (1995). *Prozessketten in der Logistik: Entwicklungstrends und Umsetzungsstrategien*. Dortmund: Verlag Praxiswissen.

Kuhn, A. (2008). “Das Modellierungsparadigma”. In: *Handbuch Logistik*. Ed. by A. Dieter, K. Axel, F. Kai, I. Heinz, and T. H. VDI-Buch. Berlin: Springer, pp. 219–224.

Obermaier, R., ed. (2016). *Industrie 4.0 als unternehmerische Gestaltungsaufgabe: Betriebswirtschaftliche, technische und rechtliche Herausforderungen*. Wiesbaden and Wiesbaden: Springer Gabler.

Roth, A., ed. (2016a). *Einführung und umsetzung von Industrie 4.0: Grundlagen, Vorgehensmodell und Use Cases in der Praxis*. Gabler.

Roth, A. (2016b). “Industrie 4.0 – Hype oder Revolution?” In: *Einführung und umsetzung von Industrie 4.0*. Ed. by A. Roth. Gabler, pp. 1–15.

Rozados, I. V. and B. Tjahjono (2014). “Big Data Analytics in Supply Chain Management: Trends and Related Research”. In: *6th International Conference on Operations and Supply Chain Management*.

Rüßmann, M., Lorenz, Markus, Gerbert, Philipp, M. Waldner, J. Justus, P. Engel, and M. Harnisch (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. Ed. by The Boston Consulting Group.

Saunders, M., P. Lewis, and A. Thornhill (2009). *Research methods for business students*. fifth edition. Harlow: Pearson Education Limited.

Schlaepfer, R. C., M. Koch, and P. Merkofer (2015). *Industry 4.0: Challenges and solutions for the digital transformation and use of exponential technologies*. Ed. by Deloitte AG.

Schlick, J., P. Stephan, M. Loskyll, and D. Lappe (2014). “Industrie 4.0 in der praktischen Anwendung”. In: *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Ed. by T. Bauernhansl, M. ten Hompel, and B. Vogel-Heuser. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 57–84.

Schrauf, S. and P. Berttram (2016). *Industry 4.0 - How digitization makes the supply chain more efficient, agile, and customer-focused*. Ed. by PwC Strategy&.

Schwab, K. (2016). *The Fourth Industrial Revolution*. Penguin Random House UK.

Seiter, M., C. Bayerle, S. Berlin, U. David, M. Rusch, and O. Treusch (2016). *Roadmap Industrie 4.0: Ihr Weg zur Erfolgreichen Umsetzung von Industrie 4.0*. Ulm: tredition.

Siepmann, D. (2016a). “Industrie 4.0 – Fünf zentrale Paradigmen”. In: *Einführung und umsetzung von Industrie 4.0*. Ed. by A. Roth. Gabler, pp. 35–46.

Siepmann, D. (2016b). “Industrie 4.0 – Struktur und Historie”. In: *Einführung und umsetzung von Industrie 4.0*. Ed. by A. Roth. Gabler, pp. 17–34.

Stebbins, R. A. (2001). *Exploratory Research in the Social Sciences*. Thousand Oaks, CA: Sage.

ten Hompel, M. and M. Henke (2017). “Logistik 4.0 – Ein Ausblick auf die Planung und das Management der zukünftigen Logistik vor dem Hintergrund der vierten industriellen Revolution”. In: *Handbuch Industrie 4.0 Bd.4*. Ed. by B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel. Springer Reference Technik. Berlin, Heidelberg and s.l.: Springer Berlin Heidelberg, pp. 249–259.

Vogel-Heuser, B., T. Bauernhansl, and M. ten Hompel, eds. (2017). *Handbuch Industrie 4.0 Bd.4: Allgemeine Grundlagen*. 2nd ed. Springer Reference Technik. Berlin, Heidelberg and s.l.: Springer Berlin Heidelberg.

Wan, J., H. Cai, and K. Zhou (2014). “Industrie 4.0: Enabling technologies”. In: *2014 International Conference on Intelligent Computing and Internet of Things (ICIT)*, pp. 135–140.

Wee, D., R. Kelly, J. Cattell, and M. Breunig (2015). *Industry 4.0: How to navigate digitization of the manufacturing sector*. Ed. by McKinsey & Company.

Wehberg, G. G. (2015). *Logistik 4.0: Komplexität managen in Theorie und Praxis*. Berlin, Heidelberg: Springer Gabler.

Wimmer, T. and C. Grotemeier, eds. (2016). *Den Wandel gestalten: 33. Deutscher Logistik-Kongress : Tagungsband*. Schriftenreihe Wirtschaft & Logistik. Hamburg: DVV Media Group GmbH.

Wischmann, S., L. Wangler, and A. Botthof (2015). *Industrie 4.0 - Volks- und betriebswirtschaftliche Faktoren für den Standort Deutschland: Eine Studie im Rahmen der Begleitforschung zum Technologieprogramm AUTONOMIK für Industrie 4.0*. Ed. by Bundesministerium für Wirtschaft und Energie. Berlin.

Wollschlaeger, M., T. Sauter, and J. Jasperneite (2017). "The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0". In: *IEEE Industrial Electronics Magazine* 11.1, pp. 17–27.

Zhang, Y., G. Q. Huang, S. Sun, and T. Yang (2014). "Multi-agent based real-time production scheduling method for radio frequency identification enabled ubiquitous shopfloor environment". In: *Computers & Industrial Engineering* 76, pp. 89–97.

Zillmann, M. and B. Appel (2016). *Keine Industrie 4.0 ohne Digitalisierung der Supply Chain: Intelligente Logistikdienstleistungen für die Fertigungsindustrie*. Ed. by Lünendonk GmbH.

Cooperation Strategies among SMEs for Implementing Industry 4.0

Julian Marius Müller[1], Lukas Maier[1], Johannes Veile[1], Kai-Ingo Voigt[1]

1 – University of Erlangen-Nuremberg

Industry 4.0 is expected to bring several conversions for industrial value creation, encompassing entire value-added networks. Small and medium-sized enterprises (SMEs), which play an important role for both the German as well as the European economy, struggle to integrate the concept of Industry 4.0 within their value creation. However, due to the high importance of SMEs for industrial value creation networks, their integration is essential to successfully establish Industry 4.0 across value chains. Several SMEs struggle to obtain the resources required for equipment and machinery or do not possess the required market shares or market access to establish new business models. Large enterprises are often seen as too powerful to be a partner for a SME. Nevertheless, cooperation strategies among SMEs may present a viable alternative to successfully implement Industry 4.0 across the value chain. In this context, literature lacks of a well-founded investigation of this topic. Therefore, this study attempts to close the present the present research gap. Due to the exploratory nature of the underlying topic, we conduct a multiple case study with 68 SMEs in Germany. This paper comes up with cooperation strategies and presents the interviewees' answers regarding potentials and challenges of common technology purchasing as well as for common business models. Subsequently, we present implications for both research and practice.

Keywords: Industry 4.0; Small and Medium-sized enterprises; Cooperation strategies; Industrial Internet of Things

1 Introduction

Industry 4.0, which is internationally known as the Industrial Internet of Things, aims to establish an intelligent, self-regulating and interconnected industrial value creation (Kang et al., 2016) ensuring future competitiveness of the manufacturing industry (Kagermann et al., 2013; Lasi et al., 2014). Given the topic's importance and actuality, research on Industry 4.0 focuses rather on technological developments related to cyber-physical systems (Brettel et al., 2014; Liao et al., 2017) than on their organizational implementation (Arnold et al., 2016; Ehret & Wirtz, 2017). Recently, scholars begin to study the value creation implications of Industry 4.0 (Kans & Ingwald, 2016; Kowalkowski et al., 2013; Rennung et al., 2016). However, according to Kowalkowsi et al. (2013), researchers investigating this topic mainly focus on large companies (Radziwon et al., 2014).

Large organizations constitute a minority, as SMEs play an important role in the overall network of industrial value creation. In the European Union, SMEs represent over 99% of all companies. Additionally, SMEs employ between 50 and 70% of all European full time equivalents and generate a gross value added share that encompasses about 50% of the European economy (Airaksinen et al., 2015; Bundesministerium für Wirtschaft und Energie, 2014).

With this paper we attempt to further examine SMEs in order to fully understand the mechanisms and implications of Industry 4.0 implementation. The legitimacy for our research lies in a lack of fundamental knowledge about Industry 4.0. along with SMEs' impact on value creation and their importance for the overall economy.

Existing literature shows that SMEs and large organizations fundamentally differ in terms of size, processes, and availability of resources (Ihlau et al., 2013). Therefore, SMEs require different strategies to successfully implement Industry 4.0 in comparison to large companies. In this context, an important question is how the characteristics of a company, such as size and resource base affect its ability to implement new technologies. For instance, the adoption of ERP systems, a technological precursor to Industry 4.0, is differently approached in SMEs and was found to be more challenging in SMEs than in large companies (Buonanno et al., 2005). Correspondingly, the implementation of Industry 4.0 tools may be more difficult in SMEs, as such companies often have lower digitization levels, caused by their operation in niche markets (Knight, 2000), their smaller production series, as well as due to their smaller production series as well as their limited access to resources and knowledge. Particularly, SMEs lack resources and knowledge that is, however, critical for the successful implementation of Industry 4.0. Existing literature shows that SMEs often cooperate with other companies to achieve better access to financial as well as personnel resources (Ihlau et al., 2013). Thus, using cooperation strategies appears to be a suitable approach for SMEs to successfully implement Industry 4.0 within an organization. However, literature provides no implications on how such cooperation strategies among SMEs should be designed and how they actually influence the implementation of Industry 4.0. That is why the aim of this study is to investigate which specific benefits as well as challenges exist regarding cooperation strategies among SMEs for implementing Industry 4.0.

2 Theoretical background

2.1 Industry 4.0

The term Industry 4.0 encompasses the expectations of politics and corporate practice that industrial manufacturing heads towards the fourth Industrial Revolution. The previous three Industrial Revolutions have achieved high productivity increases, driven by a few, fast spreading general-purpose technologies, such as mechanization, electricity and IT (Veza et al., 2015). These general-purpose technologies resulted in strong technical improvements and initiated further complementary developments (Bresnahan & Trajtenberg, 1995). The general-purpose technologies for Industry 4.0 are cyber-physical systems, whose technological infrastructure are based on the concept of the Internet of Things (Kagermann et al., 2013; Lasi et al., 2014; Xu, 2012). Cyber-physical systems are intended to establish an interconnection between the physical world and the cyber-space (He & Xu, 2015; Lee et al., 2015; Ren et al., 2013). Cyber-physical systems hereby offer mechanisms for human-to-human, human-to-object and object-to-object interactions along the entire value-added chain (Wan, 2011). Especially the task of integrating humans into this concept is perceived to be an enormous challenge as it faces employees' resistance (Frazzon et al., 2013; Gorecky et al., 2014; Hirsch-Kreinsen, 2016; Schuh et al., 2014). Humans' integration into industrial manufacturing leads to cyber-physical production systems (Schlechtendahl et al., 2015). Cyber-physical production systems enable several data-based services, such as predictive condition monitoring or balancing and reducing energy consumption within production (Lee et al., 2013; Shin et al., 2014; Tao et al., 2011).

Manufacturers place high expectations on cyber-physical production systems because they enable machinery safety, real-time control, self-organization and self-maintenance, autonomous navigation through production facilities and error predictability(Meyer et al., 2011; Monostori, 2014) along the entire lifecycle of machinery and products (Lennartson et al., 2010). Aside from cyber-physical production systems, Industry 4.0 is driven by technological developments such as service-oriented architectures (Guinard et al., 2010; Mikusz, 2016; Raja et al., 2013; Vogel-Heuser et al., 2015), which enable the creation of new services and product-service bundles (Ehret & Wirtz, 2017).

Those developments in sum result in the concept of smart production, also termed smart manufacturing (Davis et al., 2012; Feeney & Weiss, 2014; Radziwon et al., 2014; Wang et al., 2016; Zuehlke, 2010). Smart production has been discussed to be a core element of smart factories (Radziwon et al., 2014; Zhang et al., 2014). The latter use flexible and adaptive production processes to dynamically solve the problems of complex economic environments. Smart Production is characterized by manufacturing of smart, personalized products as well as high levels of collaboration through production networks, among several enterprises (Kagermann et al., 2013; Lasi et al., 2014; Veza et al., 2015; Xu et al., 2014).

Besides the German initiative Industry 4.0, the EU has initiated a public-private partnership under the title ”Factories of the Future” to achieve sustainable and competitive production in the future (European Commission, 2016). In the US, similar ideas are encouraged through the Industrial Internet Consortium with founding members such as AT&T, CISCO, GE, IBM and INTEL (Pike, 2014). The ”Internet Plus initiative” in China integrates current technological developments such as cloud computing and big data enabling state-of-the-art manufacturing (Keqiang, 2015), while South Korea has introduced the ”Manufacturing Innovation 3.0” (Kang et al., 2016).

2.2 Small and medium-sized enterprises

The term small and medium-sized entreprises refers to companies with less than 50 million Euro in sales and less than 500 employees regardless of their industry (Bundesministerium für Wirtschaft und Energie, 2013; Günterberg & Wolter, 2002). In our paper we investigate SMEs and how to implement Industry 4.0 with cooperation strategies because of several reasons:

First, potentials of Industry 4.0 can primarily be expected because of the horizontal and vertical network of the value chain. In the German industry, SMEs represent an essential part, as they represent 99,6% of all enterprises generating more than 50% of the GDP. In turn, integrating SMEs is perceived to be key to the success of Industry 4.0.

Second, existing studies show that SMEs' specific challenges differ from those of large companies. Therefore, SMEs require solutions tailored to meet their specific challenges. Management in SMEs already recognizes the importance of of Industry 4.0. However, research mainly focuses rather on large enterprises than on SMEs (Bischoff et al., 2015).

Third, the upper management of SMEs in contrast to that of large companies seems to be able to keep track of the whole enterprise. Interviewing them may reveal much information about our research topic. Further, their hierarchical position allow them to give holistic statements why SMEs qualify for examination. SMEs' managers may assess interfaces and provide both an external as well as an internal perspective (Ihlau et al., 2013).

3 Method and research design

3.1 Multiple case study

Our study's goal is to investigate potentials and challenges for cooperation strategies among SMEs for implementing Industry 4.0 and to provide an integrative, systematic, and comprehensive understanding about this topic.

In order to address this goal, we use a qualitative empirical methodology and conduct a multiple case study. We chose this methodology because it allows us to investigate the topic in a wider context, to gain a complete and holistic view, and to derive valid and generalizable results (Bryman & Bell, 2011; Gibbert et al., 2008). Asthis topic is novel, evolving, and a contemporary phenomenon, a case study design is the best method that can be used, which is especially true for research in the setting of operations or IT (Dubé & Paré, 2003; Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Voss et al., 2012; Yin, 2009). Instead of relying on a single case, we use multiple cases to increase both the robustness and the generalizability of our results (Eisenhardt & Graebner, 2007).

3.2 Data collection

We use semi-structured expert interviews with qualified and experienced managers as main source following common handling in qualitative research (Mason, 2002). Interviews of this manner allow collecting data structurally while keeping the openness that is necessary to gather all important information (Yin, 2009).

We interviewed 68 German managers of SMEs between May and July 2016 . 48 of the 68 SMEs have 100 to 500 employees, whereas 20 of the SMEs have up to 100 employees. We chose the industry sectors machine and plant engineering, electrical engineering and automotive. Our choice is based on the facts that these industries all contribute a great deal to the German Cross Domestic Product and the chosen mix well represents the industry landscape in Germany. Furthermore, the chosen industries are considered to be the ones that are most affected by and to benefit the most from Industry 4.0 (Kagermann et al., 2013). We chose Germany because of its representative character for an industrial nation, its leading economical position within the European Union and its high achievements in technological and digital development. Using a wide variety of empirical material helps to counteract negative effects of sample bias in our research (Yin, 2009).

The interviewed manager steam from middle and top management positions respectively. Those managers know the most about their firm's cooperation strategies for implementing Industry 4.0, which makes them the best suitable interview partners in our research. The interviews last between 20 and 60 minutes. In order to avoid any language barriers, we conduct the interviews in German, the mother tongue of both the interviewees and interviewers. For confidentiality reasons, we anonymize detailed case data. Corresponding to the exploratory nature of this study, the development of the interview guide was inspired by literature but followed the principle of openness and flexibility to allow unexpected and novel topics to emerge (Kasabov, 2015).

The interview guideline consists of three parts: First of all, the interviewed managers are questioned about their professional background and their areas of responsibility. In doing so, we ensure that the interview partners are suitable for the purpose of the study. Second, we ask the interviewees questions concerning potentials and challenges of cooperation strategies in technology purchasing. Third, we question the interview partners concerning potentials and challenges in jointly run new business models among SMEs . We introduce this differentiation in order to ensure the high importance of new, partner or platform based business models within the concept of Industry 4.0 (Kagermann et al., 2013; Wu et al., 2013).

3.3 Data analysis and reliability of the study

The 68 audio-recorded interviews were transcribed into text material before analyzing them. We study the transcription applying a qualitative content analysis to identify and interpret common patterns, themes, and categories (Huber & Power, 1985; Miles & Huberman, 1994). Applying an inductive coding procedure (Charmaz, 2006; Gioia, Corley, & Hamilton, 2013; Krippendorf, 2013) helpes us not to restrict our results but generate novel knowledge (Graebner & Eisenhardt, 2004). We conduct the entire coding process as a team to achieve the best interpretations and most profound understanding (Weston et al., 2001). An application of a frequency analysis following Holsti (1969) simplifies the identification of the most important potentials and challenges for cooperation strategies among SMEs. We enhance the validity and robustness of our results by applying triangulation of secondary data from annual reports and company websites to verify the interviewees' statements (Eisenhardt & Graebner, 2007; Yin, 2009). Furthermore, we assure the respondents full anonymity and confidentiality addressing potential key informant bias. The multiple case study approach supported the mitigation of the negative effects of observer bias (Eisenhardt & Graebner, 2007).

4 Results

4.1 Common technology purchasing regarding Industry 4.0

Table 1 shows the potentials for common technology purchasing regarding Industry 4.0, sorted by their frequency of naming. Our interviews indicate the reduction of financial commitment to be the most important reason for common technology purchasing. Furthermore, interviewees mention the distribution of risks, the exchange of ideas, and strengthened partnership as further potentials.

Table 2 shows the challenges for common technology purchasing regarding Industry 4.0, sorted by their frequency of naming. In this context, we found trust between partners, loss of confidential information, and coordination efforts to be the most common challenges for SMEs. Further challenges for common technology purchasing are preferred autonomy, increasing dependencies, only near-term benefits, no suitable partners, the lack of legal conditions, and reluctant behavior towards Industry 4.0.

4.2 Common business models for Industry 4.0

Table 3 shows the benefits of common business models among SMEs for Industry 4.0. We find three potentials for common business models: 24 participants mentioned the optimum usage of virtual interconnection, 20 mentioned the decrease of existing challenges through Industry 4.0, and three mentioned cost reductions.

Finally, Table 4 provides an overview of the challenges of common business models among SMEs for Industry 4.0. Overall, our results indicate nine challenges: Business model innovations are no a core competence, business model is not understood, legal uncertainty, lack of resources, no customer demand, preferred autonomy, coordination efforts, no risk diversification, and loss of flexibility.

Table 1: Potentials for common technology purchasing

Category	Frequency	Explanation
Reduction of financial commitment	33	Through the generation of compound effects and bargaining power, SMEs can reduce required financial capital.
Distribution of risks	19	Commonly purchasing distributes the risks of misinvestments among partners.
Exchange of ideas	11	Common purchasing leads SMEs to exchange ideas more openly and generate new ideas.
Strengthened partnerships	4	Through close financial ties , SMEs are able to establish new or strengthened partnerships.

Table 2: Challenges for common technology purchasing

Category	Frequency	Explanation
Trust between partners	25	Lacking trust between partners, e.g. opportunistic or dishonest behavior, hinders the implementation.
Loss of confidential information	24	In their purchasing strategy, SMEs incorporate confidential and strategic information that could be made public.
Coordination efforts	22	High coordination efforts oppose the compound effects generated by common purchasing.
Preferred autonomy	9	SMEs, especially owner-run companies, prefer autonomy in their purchasing activities.
Increasing dependencies	7	Dependencies between partners, which cannot be reversed are feared.
Only purchasing benefits	5	Common purchasing is only seen as beneficial for purchasing, not for further operations.
No suitable partners	5	The required partners are not willing to cooperate or no adequate partners exist.
Lacking legal conditions	2	The legal conditions are not fully determined for data-based purchasing within Industry 4.0.
Reluctant behavior towards Industry 4.0	2	The topic of Industry 4.0 is still unfamiliar to many SMEs.

Table 3: Potentials for common business models for Industry 4.0

Category	Frequency	Explanation
Optimum usage of virtual interconnection	24	Common business models among SMEs become viable and easy to coordinate.
Decrease of existing challenges for SMEs.	20	Establishing virtual interconnection, SMEs may gain the bargaining power and market share of larger enterprises.
Cost reductions	3	Compound effects may lead to cost reductions for all partners.

Table 4: Challenges for common business models for Industry 4.0

Category	Frequency	Explanation
Business model innovations are not a core competence	22	The development of business models is not seen as a core competence of SMEs what may hinder the development of new business models within Industry 4.0.
Business model is not understood	22	Up to now, SMEs have not fully understood the concept of business models, and thus they are mainly process or product oriented.
Legal uncertainty	17	Data-based business models come into question because of legal uncertainty regarding data theft and data property.
Lack of resources	7	As far as resources are concerned, SMEs are not seen as capable of establishing new business models.
No customer demand	7	To date, customers do not demand new business models.
Preferred autonomy	5	SMEs prefer to be independent and refrain from establishing new business models with partners.
Coordination efforts	4	The Coordination between partners is perceived to be both time and cost-intensive.
No risk diversification	3	SMEs become increasingly committed within a business model, so they are not able to diversify which in turn increases risks.
Loss of flexibility	2	SMEs might lose their core strengths such as providing individual and fast solutions, tailored to customer demands.

5 Discussion

This chapter discusses cooperation strategies to overcome SMEs' lack of resources and knowledge (Ihlau et al., 2013) and thus help to implement Industry 4.0 in their organization. In this context, commonly purchasing technologies as well as jointly developing business models are perceived to be adequate strategies, first of all examining potentials and challenges that come along with them. Keeping the results of our research in mind, the potentials and challenges can be discussed to derive implications how such cooperation strategies shall be designed to foster the implementation of Industry 4.0.

The first strategy investigated is commonly purchasing new technology among SMEs. About 37% of the interviewees mentioned a lack of trust between partners and 35% named a potential loss of confidential information, making those aspects the biggest challenges of common technology purchasing. Therefore, special attention should be given to these aspects when establishing a cooperation to make it a success. A lack of trust may stem from perceiving a partner's high negotiation power and low opportunity costs to withdraw from a cooperation. In order to establish a well-based cooperation, trust is the key to success. It is without saying that communicating trustworthily and acting reliably is the basis of a trustful cooperation. Bearing in mind not only the financial benefit, but also the importance of credibility towards partners, SMEs can act more collaboratively in negotiations. In addition, increasing its own opportunity costs by higher financial commitments on the partnership may increase the credibility of a partner.

Further, 33 % of the interviewees mention high coordination efforts in maintaining a cooperation to commonly purchase technology. This result indicates the importance of simplifying any form of cooperation to benefit comprehensively while suppressing the costs. Therefore, special attention should be drawn to interfaces in order to avoid any non-value adding processes. Automated communication and interactions, as proposed by Industry 4.0 in general, may lead to decreasing transaction costs, which in turn decreases coordination efforts. Additionally, resources may be provided to lower coordination costs for SME. Our results indicate that SMEs tend to prefer autonomy (13%) and fear increasing dependencies (10%). When setting up a cooperation, it is important to work together as closely as necessary for an adequate cooperation while respecting each partner's freedom. SME can be integrated into decisions, which may give them a sense of freedom in their decision-making process. A key aspect in this context is to create a partner's awareness for the importance of the cooperation, providing reasons for both the required efforts and the dependency and respecting the individual, often owner-based, nature of SMEs.

As a further insight, this study reveals reducing financial commitment as the most important potential of a cooperation in terms of technology purchasing. 49% of interviewees name this aspect to be vital. Another potential for common technology purchasing is the distribution of risks, mentioned by 28% of respondents. Given these aspects' importance, the emphasis should be placed on the financial benefits of the cooperation and its visibility to all partners. In this context, it seems reasonable to distribute financial benefits among partners in a fair way so that all partners involved benefit from and value the cooperation. Apart from financial benefits, an equal distribution may help to increase trust, as explained in the section before.

Lastly, the exchange of ideas is mentioned to be an important potential when cooperating among SMEs (16%) to purchase technology. Apart from the financial gains, our research reveals that one should nevertheless emphasize not primarily financial aspects. Providing the partner with knowledge about processes and sharing best-practice cases may offer further incentives to enter into a cooperation. Reciprocal exchange of knowledge does not only provide benefits for one partner, but may lead to benefits for all partners in the cooperation

Another strategy analyzed is establishing common new business models between SMEs.

In our study, we show that SMEs tend to see new business models with particular caution and there are several reasons to explain this. 33% of our interviewees state that it is not SMEs' core competence to develop business models and therefore they intend to refrain from doing so. Another reason is that SMEs may not fully understand the concept of business models. The results therefore reveal interesting insights how to cooperate among SMEs regarding Industry 4.0. First, the key to success is to properly share information. Partners with little knowledge about business models may gain the relevant knowledge just after entering a cooperation. Sharing information in a cooperation may increase total knowledge about business models. Second, apart from knowledge sharing, a cooperation allows to share resources such as working time and human capabilities. One company may not be able to develop new business models and thus have other core competences, but sharing resources in a cooperation provides the cooperating parties with the basis to do so. Last, a cooperation may help to increase the sense of urgency and the perception of business model's strategic relevance due to group effects.

Legal uncertainty is an important challenge mentioned by 25% of all interviewees as issues concerning data security and data property are present. Legal uncertainty indeed is an issue that is widely discussed in research and public opinion without a silver bullet to solve it. However, entering a cooperation bundles resources, that can be used to invest in data security, to give one example. Further, data may be stored in a decentral way, reducing the vulnerability and the probability for data loss. Last, a cooperation has more influence to ask authorities and legislation to provide SMEs with an environment that guarantees the necessary ecosystem for Industry 4.0

Our study furthermore reveals that SMEs fear, even when working together in a cooperation, to not have enough resources to create new business models (10%). The lack of resources might be an issue but working together summarizes the resource base of several companies or at least increases the possibilities to get further resources, such as external capital. Cross-subsidization with financial benefits for instance from commonly purchasing technology may help to overcome this issue.

As a potential, 35% of our interviewees name the optimum usage of virtual interconnection. 29% of the interviewees believe another potential of common business models for Industry 4.0 is the decrease of existing challenges for SMEs. In combination with cost reductions, named by 3% in our sample, especially the potentials of cost reductions and new value propositions though new business models should be fostered in a potential cooperation among SMEs to overcome the challenges named and make benefits more visible and understandable. In a second step, further benefits of common business models as its understanding within cooperating SMEs rises, could unfold.

6 Conclusion

The aim of this study was to examine cooperation strategies among SMEs for implementing Industry 4.0. We find challenges for SMEs and benefits for both technology purchasing as well as developing business models. We explain this as our interviewed SMEs are at a rather early stage in the implementation of Industry 4.0. At this stage, SMEs may not consider cooperation strategies as an important tool to support their future business. This becomes especially apparent for the challenges of joint business model development among SMEs regarding Industry 4.0, which is not seen as a core competence of SMEs as well as the concept of business models is not understood entirely by 22 out of 68 SMEs in our sample. Due to this, relatively early stage of implementation regarding Industry 4.0, where this understanding can still be generated and increased, our study presents valuable contributions for the current stage.

However, this paper is limited to a short-term perspective of cooperation strategies regarding Industry 4.0 among SMEs. Moreover, further research needs to be conducted to generalize our results in further cultural context. We recommend to further investigate cooperation strategies among SMEs within different industry sectors. A comparison with industries at a more mature stage of implementation Industry 4.0 for example the IT or software industry related to industrial production. This allows uncovering industry differences and deriving explanatory approaches.

For corporate practice, we recommend to develop new business models in context of Industry 4.0 working together in cooperation. Also, we advise to consider reorganize corporate culture such as openness to develop business models in cooperation. Further, we suggest policy makers to provide corporate practice with legal conditions such as data standards and data property supporting efforts to work in cooperation.

References

Airaksinen, A., H. Luomaranta, P. Alajaeaeskoe, and A. Roodhuijzen (2015). “Statistics on small and medium-sized enterprises: Dependent and independent SMEs and large enterprises. [online] eurostat”. In:

Arnold, C., D. Kiel, and K.-i. Voigt (2016). “How the Industrial Internet of Things Changes Business Models in Different Manufacturing Industries”. In: *International Journal of Innovation Management* 20, p. 8.

Bischoff, J., C. Taphorn, D. Wolter, N. Braun, M. Fellbaum, S. Goloverov, T. Hegmanns, C. Prasse, M. Henke, M. ten Hompel, F. Doebbeler, C. Fuss E. Kirsch, B. Maettig, S. Braun, M. Guth, M. Kaspers, and D. Scheffler (2015). “Erschliessen der Potenziale der Anwendung von Industrie 4.0 0 im Mittelstand. Studie fuer das Bundesministerium fuer Wirtschaft und Energie”. In:

Bresnahan, T. F. and M. Trajtenberg (1995). “General purpose technologies: Engines of growth?” In: *Journal of Econometrics* 65, pp. 83–108.

Brettel, M., N. Friederichsen, M. Keller, and M. Rosenberg (2014). “How Virtualization, Decentralization and Network Building Change the Manufacturing Landscape: An Industry 4.0 Perspective”. In: *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* 8, pp. 37–44.

Bryman, A. and E. Bell (2011). *Business Research Methods*. Oxford University Press: Oxford.

Bundesministerium fuer Wirtschaft und Energie (2014). “German Mittelstand: Motor der deutschen Wirtschaft”.

Buonanno, G., P. Faverio, F. Pigni, A. Ravarini, D. Sciuto, and M. Tagliavini (2005). “Factors affecting ERP system adoption: A comparative analysis between SMEs and large companies”. In: *Journal of Enterprise Information Management* 18, pp. 384–426.

Charmaz, K. (2006). *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. Los Angeles: Sage.

Commission, E. (2016). “Factories of the Future. [online] European Commission”. In: *Available at: <[Accessed* 26, p. 2017.

Davis, J., T. Edgar, J. Porter, J. Bernaden, and M. Sarli (2012). “Smart manufacturing, manufacturing intelligence and demand-dynamic performance”. In: *Computers & Chemical Engineering, (* 47, pp. 145–156.

Dube, L. and G. Pare (2003). “Rigor in information systems positivist case research: Current practices, trends, and recommendations”. In: *MIS Quarterly* 27, pp. 597–636.

Ehret, M. and J. Wirtz (2017). “Unlocking value from Machines: Business models and the industrial internet of things”. In: *Journal of Marketing Management* 30, pp. 111–130.

Eisenhardt, K. (1989). “Building theories from case study research”. In: *Academy of Management Review* 14, pp. 532–550.

Eisenhardt, K. M. and M. E. Graebner (2007). “Theory building from cases: Opportunities and Challenges”. In: *Academy of Management Journal* 50, pp. 25–32.

Feeney, A. B. and B. A. Weiss (2014). “Smart Manufacturing Operations Planning and Control, 1?6”. In: *FY* 2014.

Frazzon, E. M., J. Hartmann, T. Makuschewitz, and B. Scholz-Reiter (2013). “Towards Socio-Cyber-Physical Systems in Production Networks”. In: *Procedia CIRP* 7, pp. 49–54.

Gibbert, M., W. Ruigrok, and B. Wicki (2008). “What Passes as a Rigorous Case Study?” In: *Strategic Management Journal* 29, pp. 1465–1474.

Gioia, D. A., K. G. Corley, and A. L. Hamilton (2013). “Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology”. In: *Organizational Research Methods* 16.1, pp. 15–31.

Gorecky, D., M. Schmitt, M. Loskyll, and D. Zuhlke (2014). “Human-machine-interaction in the industry 4.0 era”. In: *Presented at the 12th IEEE International Conference on Industrial Informatics (INDIN)*. Ed. by P. Alegre.

Guenterberg, B. and H. Wolter (2002). *Unternehmensgroessenstatistik 2001/2001 Daten und Fakten*. Bonn.

Guinard, D., V. Trifa, S. Karnouskos, P. Spiess, and D. Savio (2010). “Interacting with the SOA-Based Internet of Things: Discovery, Query, Selection, and On-Demand Provisioning of Web Services”. In: *IEEE Transactions on Services Computing* 3, pp. 223–235.

He, W. and L. Xu (2015). “A state-of-the-art survey of cloud manufacturing”. In: *International Journal of Computer Integrated Manufacturing* 28, pp. 239–250.

Hirsch-Kreinsen, H. (2016). “Digitization of industrial work: Development paths and prospects”. In: *Journal for Labour Market Research* 49, pp. 1–14.

Holsti, O. R. (1969). *Content analysis for the social sciences and humanities*. Addison-Wesley: Reading.

Huber, G. P. and D. J. Power (1985). “Retrospective reports of strategic-level managers: Guidelines for increasing their accuracy”. In: *Strategic Management Journal* 6, pp. 171–180.

Ihlau, S., H. Duscha, and S. Goedecke (2013). *Spezifische Merkmale und Besonderheiten von KMU*. Wiesbaden: Springer.

Institut fuer Mittelstandsforschung (IfM) Bonn (2016). "KMU-Definition des IfM Bonn".
Kagermann, H., W. Wahlster, and J. Helbig (2013). "Recommendations for implementing the strategic initiative INDUSTRIE 4.0". In: *Final report of the Industrie Working Group. Acatech: Frankfurt am Main*.
Kang, H. S., J. Y. Lee, S. Choi, H. Kim, J. H. Park, J. Y. Son, B. H. Kim, and S. D. Noh (2016). "Smart manufacturing: Past research, present findings, and future directions". In: *International Journal of Precision Engineering and Manufacturing-Green Technology* 3, pp. 111–128.
Kans, M. and A. Ingwald (2016). "Business Model Development: Towards Service Management 4.0". In: *Procedia CIRP* 47, pp. 489–494.
Kasabov, E. (2015). "Start-Up Difficulties in Early-Stage Peripheral Clusters: The Case of IT in an Emerging Economy". In: *Entrepreneurship Theory and Practice* 39.4, pp. 727–761.
Keqiang, L. (2015). In: *Full Text: Report on the Work of the Government*.
Knight, G. (2000). "Entrepreneurship and Marketing Strategy: The SME Under Globalization". In: *Journal of International Marketing* 8, pp. 12–32.
Kowalkowski, C., L. Witell, and A. Gustafsson (2013). "Any way goes: Identifying value constellations for service infusion in SMEs". In: *Industrial Marketing Management* 42, pp. 18–30.
Krippendorff, K. (2013). *Content analysis*. Los Angeles: Sage.
Lasi, H., P. Fettke, H.-g. Kemper, T. Feld, and M. Hoffmann (2014). "Industry 4.0". In: *Business & Information Systems Engineering* 6, pp. 239–242.
Lee, J., B. Bagheri, and H.-a. Kao (2015). "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems". In: *Manufacturing Letters* 3, pp. 18–23.
Lee, J., E. Lapira, B. Bagheri, and H.-a. Kao (2013). "Recent advances and trends in predictive manufacturing systems in big data environment". In: *Manufacturing Letters* 1.1, pp. 38–41.
Lennartson, B., K. Bengtsson, C. Yuan, K. Andersson, M. Fabian, P. Falkman, and K. Akesson (2010). "Sequence Planning for Integrated Product, Process and Automation Design". In: *IEEE Transactions on Automation Science and Engineering* 7, pp. 791–802.
Liao, Y., F. De Freitas Rocha Loures, L. F. Pierin Ramos, and F. Deschamps (n.d.). "Past, present and future of Industry 4.0. a systematic literature review and research agenda proposal." In: *International Journal of Production Research* 2017.
Meyer, G. G., J. C. Wortmann, and N. B. Szirbik (2011). "Production monitoring and control with intelligent products". In: *International Journal of Production Research* 49.5, pp. 1303–1317.
Mikusz, M. (2014). "Towards an Understanding of Cyber-physical Systems as Industrial Software-Product-Service Systems". In: *Procedia CIRP* 16, pp. 385–389.
Miles, M. B. and A. M. Huberman (1994). *Qualitative Data Analysis. An Expanded Sourcebook*. Sage: London.
Monostori, L. (2014). "Cyber-physical Production Systems: Roots, Expectations and R&D Challenges". In: *Procedia CIRP* 17, pp. 9–13.
Pike, J. (2014). "AT&T, CISCO, GE, IBM and INTEL Form Industrial Internet Consortium to Improve Integration of the Physical and Digital Worlds: Technology leaders drive industry ecosystem to accelerate more reliable access to big data to unlock business value. [online] Industrial Internet Consortium". In: p. 2017.
Radziwon, A., A. Bilberg, M. Bogers, and E. S. Madsen (2014). "The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions". In: *Procedia Engineering* 69, pp. 1184–1190.
Raja, J. Z., D. Bourne, K. Goffin, M. Cakkol, and V. Martinez (2013). "Achieving customer satisfaction through integrated products and services: An exploratory study". In: *Journal of Product Innovation Management* 30, pp. 1128–1144.

Ren, L., L. Zhang, F. Tao, C. Zhao, X. Chai, and X. Zhao (2013). "Cloud manufacturing: From concept to practice". In: *Enterprise Information Systems* 9, pp. 186–209.

Rennung, F., C. T. Luminosu, and A. Draghici (2016). "Service Provision in the Framework of Industry 4.0". In: *Procedia - Social and Behavioral Sciences*, pp. 372–377.

Schlechtendahl, J., M. Keinert, F. Kretschmer, A. Lechler, and A. Verl (2015). "Making existing production systems Industry 4.0-ready". In: *Production Engineering* 9, pp. 143–148.

Schuh, G., T. Potente, C. Wesch-Potente, A. R. Weber, and J.-p. Prote (2014). "Collaboration Mechanisms to Increase Productivity in the Context of Industrie 4.0". In: *Procedia CIRP* 19, pp. 51–56.

Shin, S.-j., J. Woo, and S. Rachuri (2014). "Predictive Analytics Model for Power Consumption in Manufacturing". In: *Procedia CIRP*, pp. 153–158.

Tao, F., L. Zhang, V. C. Venkatesh, Y. Luo, and Y. Cheng (2011). "Cloud manufacturing: A computing and service-oriented manufacturing model". In: *Proceedings of the Institution of Mechanical Engineering*. J. Engineering Manufacture, pp. 1969–1976.

Veza, I., M. Mladineo, and N. Gjeldum (2015). "Managing Innovative Production Network of Smart Factories". In: *IFAC-PapersOnLine* 48, pp. 555–560.

Vogel-Heuser, B., A. Fay, I. Schaefer, and M. Tichy (2015). "Evolution of software in automated production systems: Challenges and research directions". In: *Journal of Systems and Software*, pp. 54–84.

Voss, C., N. Tsikriktsis, and M. Frohlich (2002). "Case research in operations management". In: *International Journal of Operations and Production Management* 22, pp. 195–219.

Wan, J. (2011). "Advances in Cyber-Physical Systems Research". In: *KSII Transactions on Internet and Information Systems* 5, p. 11.

Wang, S., J. Wan, D. Zhang, D. Li, and C. Zhang (2016). "Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination". In: *Computer Networks* 101, pp. 158–168.

Weston, C., T. Gandell, J. Beauchamp, L. McAlpine, C. Wiseman, and C. Beauchamp (2001). "Analyzing interview data: The development and evolution of a coding system". In: *Qualitative Sociology* 24.3, pp. 381–400.

Wu, J., B. Guo, and Y. Shi (2013). "Customer knowledge management and IT-enabled business model innovation: A conceptual framework and a case study from China". In: *European Management Journal* 31, pp. 359–372.

Xu, L. D., W. He, and S. Li (2014). "Internet of Things in Industries: A Survey". In: *IEEE Transactions on Industrial Informatics* 10, pp. 2233–2243.

Xu, X. (2012). "From cloud computing to cloud manufacturing". In: *Robotics and Computer-Integrated Manufacturing* 28, pp. 75–86.

Yin, R. K. (2009). *Case Study Research: Design and Methods. 4th edn*. Sage Publications: London.

Zhang, Y., G. Zhang, J. Wang, S. Sun, S. Si, and T. Yang (2014). "Real-time information capturing and integration framework of the internet of manufacturing things". In: *International Journal of Computer Integrated Manufacturing* 28, pp. 811–822.

Zuehlke, D. (2010). "SmartFactory: Towards a factory-of-things". In: *Annual Reviews in Control* 34, pp. 129–138.

Design of a Cyber-Physical Production System for Semiconductor Manufacturing

Sophia Keil[1]

1 – Technische Universität Dresden

Due to the highly dynamic markets, an increasing complexity, and individualization of products, efficient and robust logistical processes are difficult to achieve through the use of central planning and control approaches. The aim of the contribution is the design of a decentralized, autonomous control system for high tech production systems. An interdisciplinary perspective was adopted as methods of artificial intelligence and mechanical as well as electrical engineering were used. The results are a hardware concept for an intelligent, cyber-physical production lot and a software concept based on a hierarchical multi-agent architecture. The basic idea of autonomy and self-control is not new. It can be traced back, for example, to the ideas of "Evolutionary Management", or cybernetics.

However, for the first time this contribution shows a practical application for a complex semiconductor manufacturing system. Until now, the hard and software concepts have been implemented prototypically. A long-term integration into the existing IT landscape of a semiconductor factory is planned. A well established and functioning centralized system should be supplemented by the new decentralized system, especially in areas in which there is not yet such a high level of automated processes, e. g. in wafer test facilities.

Keywords: cyber-physical production system; multi-agent system; intelligent production lot; semiconductor manufacturing

1 Introduction

Competitive semiconductor companies need to deliver high quality products in a fast, timely, and cost-efficient manner in the context of highly dynamic markets, which are characterized by rapidly declining prices, short product life cycles, and a high frequency of technology changes (Sonar et al., 2013). Short product life cycles, an increasing complexity, and individualization of products, which are usually provided in a high number of variants, lead to sophisticated requirements with respect to logistics processes and systems. Hereby, centrally controlled systems reach their limits concerning their capabilities to deal with the arising complexity to plan, control, and monitor changeable systems (Schuhmacher and Hummel, 2016). Ten Hompel (2010) proposes the adoption of individualization as a design principle for logistics processes and systems. A key approach in this context is the concept of self-control. Self-controlled systems promise the advantages of increased (Brettel et al., 2014)

- flexibility, in terms of changeability of the system;
- robustness, as the decision-making competence is shifted to individual logistical objects; and
- data availability as well as transparency of complex material flow structures.

Self-control includes two main concepts: decentralization and autonomy. The degree of decentralization indicates on which system level control decisions are made. Self-control is attained when the degree of decentralization reaches the level of the physical material flow. That means the individual logistical objects such as the goods to be transported and the load carriers, but also the transport systems, make autonomous control decisions. The degree of autonomy indicates how many decision making opportunities the individual logistic object has. A prerequisite for the realization of self-controlled systems is a certain level of intelligence, which is realized by ICT technologies and, more importantly, cyber physical systems (Scholz-Reiter et al., 2005).

Following these thoughts, the main research question of the contribution is as follows: How should a cyber-physical production system for the semiconductor industry be designed to enable manufacturing excellence? To answer the question, the paper is organized in the following manner: after this introduction, Section 2 includes a short overview about the theoretical background of Cyber-Physical

Systems and Cyber-Physical Production Systems as well as existing research and industrial approaches. Section 3 comprises a characterization of the case study of semiconductor production. Section 4 includes the design of a semiconductor manufacturing specific CPPS, including with the software and hardware concept as well as a validation of the concept. Lastly, a summary and outlook for future tasks are put forth.

2 Theoretical Background

2.1 Cyber-Physical Production Systems

Figure 1 shows the structure of a Cyber-Physical System (CPS) schematically. Within a manufacturing system, an embedded system in the sense of a CPS is integrated within physical systems, e. g. the machines or production lots. The embedded system includes sensors to gather physical data and electronic hardware as well as software to save, and analyze data. The results of the data processing are the foundation for an interplay with other physical or digital systems by means of actuators (Lee et al., 2015). Furthermore, a CPS comprises a human machine interface, e. g. for exchange of information and supervision (Geisberger and Broy, 2015). A cyber-physical production system (CPPS) can be formed when numerous cyber-physical systems are linked and cooperate through digital networks (Seitz and Nyhuis, 2015).

CPSs are intelligent objects of class 4 as they are characterized by the features: identification, memory capacity, data processing and interaction/ communication (Zbib et al., 2008). Thereby, CPSs enable the design of intelligent logistics systems, where autonomous self-control is one characteristic of intelligent systems (Reinhart et al., 2013; Ostgathe, 2012). Further characteristics of intelligent systems are described in the following Section 2.2.

2.2 Characteristics of Intelligent Systems

In order to understand artificial intelligence within systems, it is useful to first characterize human intelligence, which cannot be described by a single feature. During a symposium held in 1986, experts provided answers to the question what

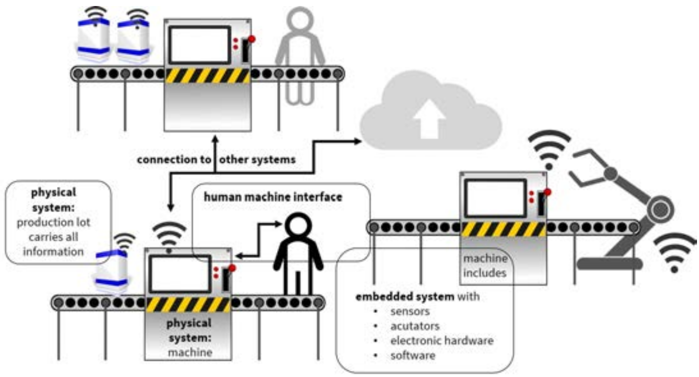

Figure 1: Structure of a CPS

human intelligence is (Sternberg and Detterman, 1986). These experts most frequently used the following characteristics to define the concept of intelligence:

First, intelligence involves elementary processing processes (perception, sensitivity, attention). Individuals must be able to perceive their environment, have knowledge, and then reach a higher level of processing, such as logical conclusions, imagination, problem solving, and judgments. In addition, the adaptability to a changing environment belongs to the concept of intelligence. Kail et al. (1988) analyzed numerous definitions of human intelligence. They found that most definitions include the ability of humans to think abstractly and to reason and derive purposeful actions from it.

The dimensions of thinking and action are also considered in the research field of artificial intelligence (AI). There are two approaches: First, researchers can try to understand how human beings think and act, and then model or simulate it on a computer. Second, the researcher tries to find an optimal approach independent of how humans would solve the problem, which would be represented by the rational view. A system is rational when it does the right thing according to its own knowledge (Russel and Norvig, 1995). Thereby, strong and weak AI are distinguished. The aim of strong AI is to develop AI to the point where the machine's intellectual capability is functionally equal to a human's or even surpasses it, e.g. Blue Brain Project. Weak or narrow AI is machine intelligence that is limited to specific application domains, e.g. expert systems (Russel and Norvig, 1995; Ertel, 2009)

In general, intelligent systems should be autonomous, proactive, adaptive, self-explanatory, fault-tolerant, self-optimizing, adaptive, goal-oriented, flexible, and cooperative. There is no system worldwide that maintains all of these features; but if none of these features are present, the system is also not considered intelligent (Wahlster, 2013).

Autonomy is a main feature of self-controlled systems. Methodological approaches with respect to self-control have already existed for many years. They can be regarded from different scientific perspectives. According to the system's perspective, a system can be divided into the levels decision system, information system, and execution system (Ropohl, 1979). The research with respect to logistics systems includes the self-controlled physical flow of materials and goods and their accompanying information flow and technology realization as well as the management of self-organizing logistics processes (Freitag et al., 2004).

The decision system is reflected by the management and organization literature (Windt, 2006), with a major research area focusing on the Evolutionary Management approach. Hereby, researchers transfer approaches of the evolution of natural organic systems to the evolution of enterprises (Malik and Probst, 1984). The information and execution system are reflected by research in the areas of science, technology, engineering, and mathematics. Hereby, two major approaches are to apply swarm intelligence and multi-agent systems (MAS) (Windt 2006; Scholz-Reiter and Höhns, 2006, Monostori, 2014; Wang et al., 2015). Examples for the application of swarm intelligence and MAS in the context of CPPS are the research projects CoCos, InnoCyFer, and SMART FACE (Bundesministerium für Wirtschaft und Energie, 2016). The research projects show that agent technology is a promising approach to implementing a decentralized and autonomous production controlling system. Therefore, it will be used to achieve the research goal of designing a self-controlled production system for semiconductor manufacturing (Section 4.1). A characterization of semiconductor manufacturing is described in the following Section 3.

3 Characterization of the Case Study of Semiconductor Production

3.1 Manufacturing Organization within the examined Factory

Generally, semiconductor fabrication facilities are organized in a job shop (Chien et al. 2016, Chen et al., 2008; Puffer, 2007). Here, the manufacturing tools are clustered according to their function. This enables high capacity utilization, but causes rather long lead times in contrast to the organization according to flow production where the installation of machines follows the product workflow (Miltenburg, 2005).

In the investigated factory, the job shop manufacturing organization is reflected in the bay-chase fab layout. The production floor is structured into different bays, the “job shops”. Each of these shops comprises similar types of machines, which accomplish one function (Meyersdorf and Taghizadeh 1998; Chang and Chang 1998). These production bays, which are also called intrabays, are linked to a connecting corridor, the interbay (see Figure 2). Between the bays are maintenance chases (grey room) (Chien et al. 2016). Besides, Figure 2 shows also elements of the Automated Material Handling System: stocker and lifts, which are described in the Section 3.2.

3.2 Material Handling System within the examined Factory

The following explanations describe the Automated Material Handling System (AMHS) of the investigated semiconductor company. This is necessary since the individual system elements are part of the decentralized control system to be designed. Within the company it is called the wafer transport system. Wafers represent the raw material for the production of Integrated Circuits (ICs). They are formed of highly pure (99.9999999% purity), single crystalline material (Winzker, 2008).

The task of the wafer transport system is to connect the various production areas with a material handling technique. For this purpose, a defined transport unit is transported in carriers from work station to work station. Main components of the wafer transport system are (Deutschländer et al., 2005; Heinrich and Pyke, 1999):

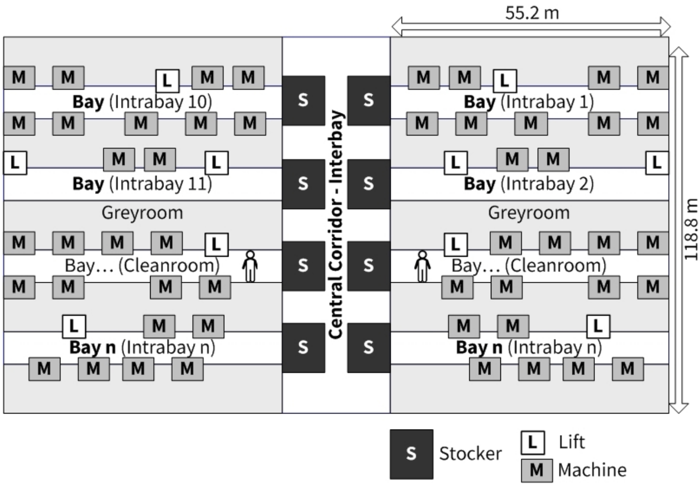

Figure 2: Bay-Chase Facility Layout

Figure 3: Part of the conveyor AHMS – depicting open carrier transportation on top left (Courtesy of Infineon Technologies Dresden GmbH)

conveyor, carrier, lift, lower and upper buffer, stocker, and the Material Controlling System (MCS).

Linking the production machines is carried out by a conveyor. On the conveyor tracks, open carriers move at a speed of 0.23 m/sec. The total length of the conveyor is 4.2 km, which is installed on the ceiling of the clean room. The transport and the machine processing are divided into two different levels. This results in a high machine density in the clean room area. The height difference is 2.70 m from the floor (machine processing level) to the transport level at the ceiling (see Figure 3) (Niekisch, 2001). Carriers are used as conveying aids (see top left of Figure 3). They can hold 25 wafers each. This transport unit corresponds to a production lot.

Each carrier can be tracked (conveyor path, current location) by means of carrier identification. The lot number and carrier identification are stored in the memory chip of the carrier. Lifting and lowering stations connect the transport with the shop floor level. These technical devices, hereinafter referred to as lifts, are typically arranged near the production machines to minimize handling efforts (Niekisch, 2001).

For the purpose of synchronization of consecutive process steps within the manufacturing processes, storage devices, so called buffer, are installed in the semiconductor factory. They are arranged in the immediate vicinity of a lift. If the buffer nearby the machine is being used to capacity, the lots are stored in stockers which are directly located in front of a production bay (Niekisch, 2001). The existing central production control system is a Manufacturing Execution System (MES) based on legacy Workstream, which is a trademark of the firm Applied Materials (Heinrich and Pyke, 1999).

4 Design of a CPPS for Semiconductor Industry

4.1 Multi-agent oriented Software Concept

As described in Section 2.2, the agent technology is a promising approach to implementing a decentralized and autonomous production control system. In agent technology, a multi-agent system (MAS) is seen as a society of independent actors which solve different tasks under competition or in cooperation (Bussmann et al., 2004). A software agent can be described as *“a self-contained program capable of controlling its own decision making and acting, based on its perception of its environment, in pursuit of one or more objectives”* (Jennings and Wooldridge, 1996, p. 1). A set of interacting agents is referred to as an MAS (Bussmann et al., 2004). In the case of software agents, the interaction is based in particular on the exchange of messages, while in robotics the common physical work is also considered (Scholz-Reiter and Höhns, 2006). A generally accepted definition for MAS and their applications in complex production systems has not been established to this day. Rather, the agent is characterized by its role, tasks, and the skills required for it. Wooldridge and Jennings (1995) name four properties which are a basic prerequisite for agents:

- Autonomy: agents run sans involvement of people and have control with respect to their activities and condition (Castelfranchi, 1994);
- Social ability: agents work together with other agents (also people) through an agent communication language (Genesereth and Ketchpel, 1994);
- Reactivity: agents notice their surrounding conditions and respond to variations; and
- Pro-activeness: agents are able to show purposeful behavior, grasping the nettle.

For the design of the MAS, the Process for Agent Societies Specification and Implementation (PASSI) approach was applied which includes five models: systems requirements model, agent society model, agent implementation model, code model, deployment model (Cossentino and Seidita, 2014). Exemplarily, the system requirements model is described in the following, as this model is the major input parameter for all the other models. A hierarchical agent society was chosen,

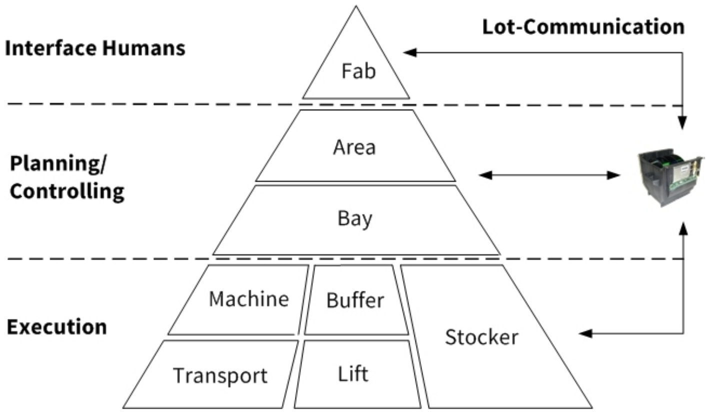

Figure 4: Hierarchical Agent Society

as this is the standard approach for production control of complex production systems, such as semiconductor manufacturing (Mönch and Stehli, 2006).

Figure 4 shows the three main levels of the system pyramid consisting of

— Interface Humans

— Planning/Controlling

— Execution

The top level of the pyramid, "Interface Human", is used to monitor and control the entire system by humans. This allows them to access the system directly, supported by the fab agent. For this purpose, a graphical interface is provided which visualizes the status of the fabrication facility and offers the possibility of interacting with the system. The planning and controlling level follows the thoughts described in Keil et al. (2011). Hereby, the lot agent plays a central role and is provided with a clock based production schedule and cumulative quantities (Löding, 2008) by the area agent. Based on the schedule, the lot agent negotiates with the identified agents, e. g. with the bay agent regarding the processing capability.

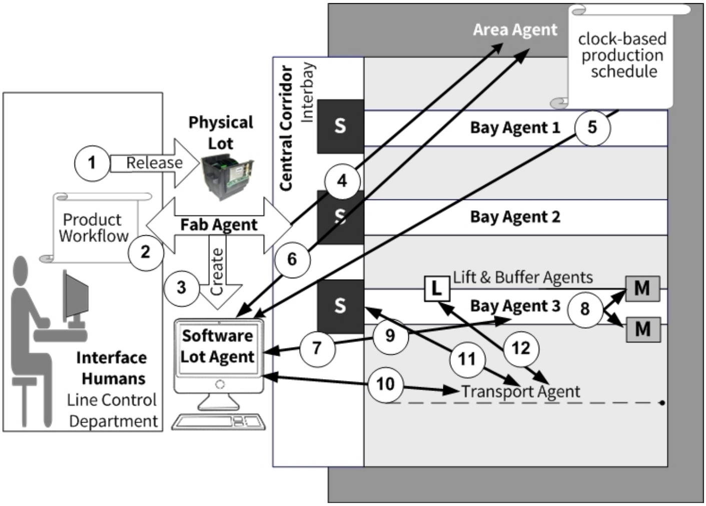

Figure 5: Hierarchical Agent Society and roles according to PASSI

The lot agent is able to communicate over all levels of the pyramid. He can act directly in the event of disruptions or deviations from the plan. In addition, the lot agent is able to perceive its environment by means of corresponding hardware at the carrier, which is described in Section 4.2. This enables the lot agent to react quickly to external influences.

Figure 5 shows exemplarily the negotiation relationships between the agents. At the interface between the human and the fab agent, the employee physically releases a production order (lot) (1) and renders the product workflow (2) of the product to the fab agent. The fab agent creates a software lot agent (3). Afterwards, the fab agent communicates with the area agent and asks him to create a clock-based production schedule for the new lot (4). The software lot agent gets the production schedule from the area agent (5). Based on this schedule, the lot agent asks the area agent which bay agent is responsible for the needed first production step (6). After receiving the answer, the lot agent asks the responsible bay agent to offer him production capacity in a certain time frame with respect to

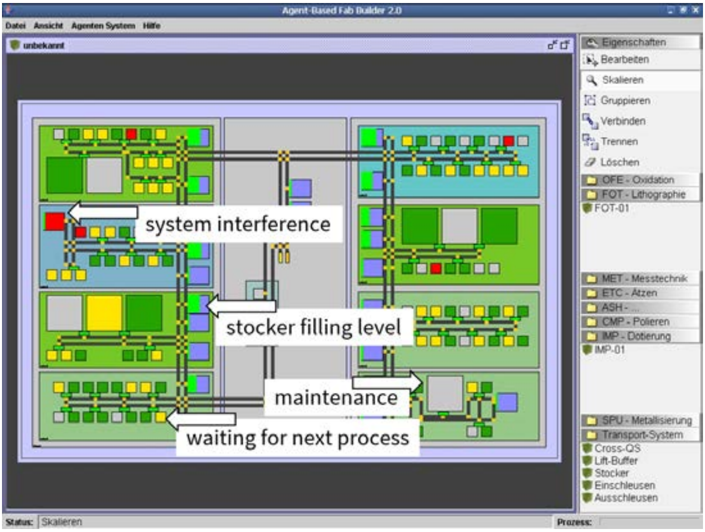

Figure 6: FAB-Monitor for visualization of the status characteristics of the semiconductor factory

a certain production recipe (7). For example, the bay agent asks for two machines in his bay which are able to carry out the needed production step (8). Maybe machine 1 responds: “I am down due to a failure” and machine 2 says: “currently, I am carrying out production step x, but in 50 minutes I will be available”. Then the bay agent offers the capacity to the lot agent, who accepts the offer (9). Now, the lot agent asks the transport agent: “could you transport me to bay x, and lift y?”. Maybe the transport agent says “yes, in 30 minutes, I can take you to the destination and in the meantime I will transport you to stocker y for an intermediate storage” (10).

In the background, the transport agent has asked the responsible stocker agent with respect to his capacity for temporary storage (11). Furthermore, the transport agent organizes the transport of the lot from the stocker to a buffer nearby a lift and the transport to the operation level by the respective lift (12).

The JADE (Java Agent Development Framework) was selected as an appropriate framework for implementing the presented MAS as it is in compliance with the Foundation for Intelligent Physical Agents (FIPA) which offers generic agent technologies. Thus, the communication with other agent platforms is safeguarded and the integration effort is decreased (Bellifemine et al., 1999; Bellifemine et al., 2008). The realization of the MAS occurred in two steps. Hereby, the production system was implemented in the first step. This enabled the modeling of a semiconductor factory and to feed in production orders. For the visualization of these tasks, the visualization tool ”FAB-Monitor” was designed (see Figure 6), which directly represents the activities of the MAS. Hereby, at the “interface humans” the employees can see, for example, which machines are in maintenance or where system interferences actually occurred. Unlike traditional visualization tools which are based on a central data structure, the newly deployed decentralized solution does not rely on a higher-level node. The advantages lie in the relief of the entire system as well as in a maximum topicality of the visualized data.

In the second step, the module for the planning of production orders was developed. For this purpose, current manufacturing data, such as machine failures, capacity bottlenecks, and processing times, are used. These data are provided by the lot agent, the hardware concept of which is described in Section 4.2.

4.2 Hardware Concept for a Cyber-Physical Production Lot

The goal is to develop a cyber-physical production lot. Therefore, a microcomputer with communication technology, a sensor system, and a power supply is integrated into the wafer carrier. For the receiving, evaluation, and further processing of the sensor data, access points are used. These access points are supplied with energy by means of Power over Ethernet. The hardware concept, which is schematically illustrated in Figure 7, is discussed in detail below.

To determine the processing times of the single production steps, it is necessary to measure the time span from the removal of the first wafer to the completion of the last wafer. For this purpose, forked light barriers are located in each slot of the carrier, which can detect the presence of a wafer. The data of the sensors are collected by an ATMega32 microcontroller from the firm Atmel. This controller communicates via the SPI interface with another microcontroller, an NA1TR8 of the firm Nanotron Technologies. This controller is responsible for the evaluation, conversion, and transmission of the collected sensor data.

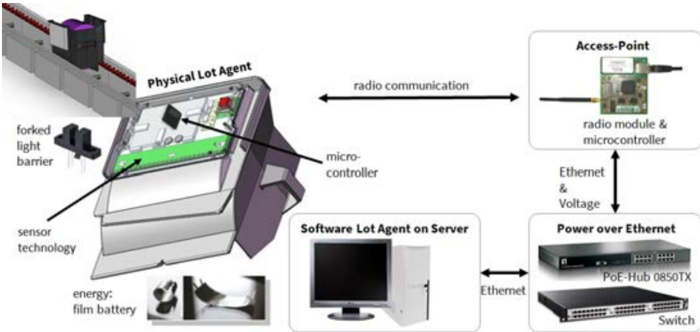

Figure 7: Hardware Concept of the Cyber-Physical Production Lot (CPPL)

The data are transmitted using the approach Chirp Spread Spectrum (CSS), which is part of the Multi Dimensional Multiple Access (MDMA) approach. This method provides high data transfer rates and extremely low power consumption and was included in the NA1TR8 controller by the company Nanotron Technologies (Nanotron, 2017).For the purpose of easy handling, all electronics (ATMega32, NA1TR8, SMD antenna, and other components) are located on one circuit board with dimensions of 95 x 20 x 4 mm (width x height x depth). An additional circuit board is required for the sensors and their control electronics.

For the power supply, film batteries are used which have a depth of about 3 mm. In order to guarantee sufficient energy supply over a period of 50 days (approximate cycle time of a lot), two batteries with 430 milliampere hours (mAh) capacity each are required. Since the weight of the batteries together is about 27 grams, and the cassette must be balanced, the batteries are attached to the opposite carrier wall.

Access points are available to receive data sent from the sensor nodes. Due to the absence of high transmission power, it is necessary to install several access points in the semiconductor factory. The hardware of the access points consists of a radio module from Nanotron Technologies and a microcomputer (PXA270), which was provided by the company Phytec. This microcomputer has the full functionality of a personal computer. On the Linux operating system, a program for receiving and evaluating data is installed. This data can be forwarded to the requesting agent via Ethernet. The concept of Power over Ethernet is used for power supply. Hereby, the data is provided and at the same time the voltage is supplied via a single Ethernet cable. Thus, no further power supply cable with adaptor is necessary, which significantly increases the flexibility with respect to the positioning of the access points.

The described hardware concept can be easily expanded if new functions are required. Further steps include, for example, the function perceiving the surroundings of the carrier by means of further sensor technology. Thus, for example, ”lost” wafers can be detected at an early stage after cleaning operations. This contributes to a stability of production processes, since disturbances can be detected at an early stage. A task of the microcomputer is the collection of all essential processing data of the lot. This ensures, on the one hand, the actuality of the data and, on the other hand, the achievement of a high maturity level of technological processes. Development, process, maintenance, and product engineers have the opportunity for easy data evaluation since all collected data (e.g. process temperatures, end point times, processing and material flow times) are available for one lot at one location. This allows quick decisions and reactions of the engineers. In addition, the ”intelligent” lot, which is equipped with the microcomputer, is able to carry out the tasks of production scheduling independently on the basis of predetermined targets.

4.3 Validation of the Concept

The validation of the concept includes three important aspects:

- Design and test of the radio network in the semiconductor factory,
- Integration of the carrier with the new electronic components in the existing factory, and
- Integration of the MAS in the exiting IT landscape

To point 1: Since the software lot agent runs on a server and not on the physical production lot carrier like the sensor technology, the communication between the carrier and the server must take place via a radio network. Therefore, the construction of a stable radio network is an important prerequisite for the implementation of the concept. As described in Section 4.2, the data is transmitted via the MDMA approach, which enables low energy consumption in contrast to other technologies like WLAN, Bluetooth, or ZigBee (Masini, 2015). This is of critical importance since the physical production lot agent stays in the factory for about 50 days.

In a first step, the transmission quality had to be determined. A measurement was carried out in the laboratory of the University of Applied Sciences Stralsund under the following conditions:

— line of sight between transmitter and receiver: distance 80 meters,

— without direct line of sight between transmitter and receiver: distance 40 meters, and

— without a visual connection through a wall: distance 8 meters.

The results of the measurements did show that an acceptable transmission quality exists at a transmission power of 8 dBm and a distance of 40 m without a visual connection. Due to tolerances and possible interferences, the distance between an access point and a sensor node should not exceed 30 meters. Based on these results, a statement about the positioning of the access points in the semiconductor factory can be made. As an intrabay has a length of 55.3 meters (see Figure 2), one access point is integrated in the middle of each intrabay. Additional access points in the interbay enable communication between several intrabays. 38 access points are required for the entire production system.

In a second step an access point was positioned in an intrabay of the regarded semiconductor manufacturer. The field test in the company did show that some of the machines emit interfering electromagnetic fields. Therefore, in the following field tests it is necessary to separately determine the transmission quality in each intrabay. If there is a reduced transmission quality, additional access points must be stationed in the respective intrabay. In addition, a possible negative impact of the radio waves on the machines has to be investigated.

An alternative to the described radio network based on the MDMA approach would be to use the existing WLAN network of the company or to use the radio network of a network operator. Then a new energy concept for the cyber physical production lot would have to be designed, as the data transmission within these networks would consume more energy. One alternative approach to solving the energy issue would be to load the carrier during the waiting times in the stocker.

To point 2: Due to clean room requirements, the carrier has to be cleaned approximately every 100 days. Therefore, in a second step, a watertight box, which includes the electronic components, was designed. In general, several thousand carriers are used in the production system. When the system is introduced into the factory, the company would have to ask the carrier supplier to integrate the electronics into the carrier during the manufacturing of the carrier. Furthermore, the retrofitting of the system requires rather high investment costs. In general, there is more than one solution for the technical realization of the cyber physical production lot. The realization depends on the material flow technique used in the respective company.

To point 3: The MAS system currently works in a simulation environment. So far, the focus has been set on the visualization of factory status (see Figure 6). Until now, about 100 production lots have been introduced into the system. The next steps are to examine the system behavior with respect to lead times and capacity utilization at a more realistic number of several thousand production lots. A huge challenge is the connection of the MAS to the existing material execution system. As the existing dispatch rules cannot be overridden due to the risk of loss of production for the firm, a step-by-step approach is required. It is proposed to use the new cyber physical production system in less automated production areas. For the semiconductor industry this would be factories that test wafers. In those factories the functionality of the manufactured products is tested, e.g. with respect to electrical parameters or through stress tests.

5 Summary and Outlook

The megatrends toward individualization of products and shorter delivery times together with rising cost and efficiency pressures, lead to an increasing complexity with respect to the organization, planning and control of production processes. Through the development and introduction of CPPS, this trend can be countered. By using the example of semiconductor manufacturing, a decentralized and autonomous production controlling system based on multi agent technology supported by a cyber-physical production lot was presented.

The sensor technology within the cyber-physical production lot enables data collection, which enhances the transparency of the production system. For example, in case of disturbances, employees can react fast and negative effects on other products can be avoided. This is achieved by the presented fab monitor, which visualizes the data collected by the lots. In general, the presented lot agent can enhance the data quality for production planning and control. Nevertheless, new production control strategies and accompanying technologies do not replace the need for designing lean processes. Furthermore, the next step is to design a control system for production networks.

Although the technology for CPPS is available, production systems of firms cannot be changed from day to day as it is challenging to integrate advanced production control strategies into legacy software systems of firms. Here firm specific transition concepts are needed.

For the future, it is of major importance to answer the question how the role of the human is defined in a CPPS as job profiles and the work division between CPPS and the humans will alter in the face of the technical progress. In addition, organizational forms have to be changed to facilitate decisions of employees, e.g. by swarm organizations and flat hierarchies, which reflect the decentralization, and autonomy in CPPS.

Acknowledgements

The development work was pursued under the leadership of Arthur Deutschländer, Sophia Keil and Mathias Kuttig at the University of Applied Sciences Stralsund with the support of Robert Kohn, Andreas Nack, Christoph Nagel, Ricardo Mussehl, Lars Böcker, Diana Riemer and Bernd Rummler. Thanks a lot to the employees of the company Infineon Technologies Dresden GmbH, especially Germar Schneider and Harald Heinrich who supported the work.

References

Bellifemine, F., G. Caire, A. Poggi, G. Rimassa, and A. Jade (2008). “A white paper”. In: *Telecom Italia EXP magazine* 3.

Bellifemine, F., A. Poggi, and G. Rimassa (1999). “JADE–A FIPA-compliant agent framework”. In: *Proceedings of PAAM (Vol. 99, No. 97-108, p. 33)*.

Brettel, M., N. Friederichsen, M. Keller, and M. Rosenberg (2014). “How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective”. In: *International Journal of Mechanical, Industrial Science and Engineering* 8.1, pp. 37–44.

Bussmann, S., N. R. Jennings, and M. J. Wooldridge (2004). *Multiagent systems for manufacturing control: a design methodology*. Science & Business Media: Springer.

Castelfranchi, C. (1994). “Guarantees for autonomy in cognitive agent architecture”. In: *International Workshop on Agent Theories, Architectures, and Languages*. Berlin Heidelberg: Springer, pp. 56–70.

Chang, C. F. and S. K. Chang (1998). "A layer-based layout approach for semiconductor fabrication facilities". In: *Advanced Semiconductor Manufacturing Conference and Workshop*. IEEE/SEMI, pp. 385–390.

Chen, J. C., R. D. Dai, and C. W. Chen (2008). "A practical fab design procedure for wafer fabrication plants". In: *International Journal of Production Research* 46.10, pp. 2565–2588.

Chien, C. F., C. H. Hu, and Y. F. Hu (2016). "Overall Space Effectiveness (OSE) for Enhancing Fab Space Productivity". In: *IEEE Transactions on Semiconductor Manufacturing* 29.3, pp. 239–247.

Cossentino, M. and V. Seidita (2014). "PASSI: Process for agent societies specification and implementation". In: *Handbook on Agent-Oriented Design Processes*. Ed. by Springer. Berlin Heidelberg, pp. 287–329.

Deutschländer, A., G. Brückner, H. Heinrich, and S. Keil (2005). "Materialflussautomatisierung unter Einsatz von Robotern in der Halbleiterfertigung mit 200 mm-Wafer-Technologie". In: *Logistik Management, Innovative Logistikkonzepte*, pp. 241–255.

Ertel, W. (2009). *Grundkurs Künstliche Intelligenz*. Wiesbaden.

Freitag, M., O. Herzog, and B. Scholz-Reiter (2004). "Selbststeuerung logistischer Prozesse – Ein Paradigmenwechsel und seine Grenzen". In: *Industrie Management* 20.1, pp. 23–27.

Geisberger, E. and M. (Broy (2015). *Living in a networked world: Integrated research agenda Cyber-Physical Systems (agenda CPS)*. Herbert Utz Verlag.

Genesereth, M. R. and S. P. Ketchpel (1994). *Software agents*. Tech. rep. Center for Integrated Facility Engineering. Stanford University.

Heinrich, H. and A. Pyke (1999). "The Impact of Conveyor Transports on Factory Performance at Infineon's (Siemens) 200 mm Fab". In: *Semiconductor Fabtech* 10, pp. 15–18.

Hompel, M. ten (2010). *Individualisierung als logistisch-technisches Prinzip. Internet der Dinge in der Intralogistik*. Berlin Heidelberg: Springer.

Jennings, N. and M. Wooldridge (1996). "Software agents". In: *IEE review* 42.1, pp. 17–20.

Kail, R., J. W. Pellegrino, and A. Hildebrandt-Essig (1988). *Menschliche Intelligenz*. Heidelberg: Verlag Spektrum der Wissenschaft.

Keil, S., D. Eberts, T. Igel, G. Schneider, K. Wilhelm, R. Lasch, and A. Deutschländer (2011). "Innovation and manufacturing excellence in mature multi product semi-conductor fabrication facilities via design for flow by 3". In: *Semiconductor Conference Dresden (SCD)*, pp. 1–5.

Lee, J., B. Bagheri, and H. A. Kao (2015). "A cyber-physical systems architecture for industry 4.0 based manufacturing systems". In: *Manufacturing Letters* 3, pp. 18–23.

Lödding, H. (2008). *Verfahren der Fertigungssteuerung: Grundlagen, Beschreibung, Konfiguration*. Berlin: Springer Verlag.

Malik, F. and G. Probst (1984). "Evolutionary management". In: *Self-organization and management of social systems*. Ed. by S. B. Heidelberg, pp. 105–120.

Masini, M. (2015). *Störungsunempfindliche Informationsübertragung in dynamischer Produktionsumgebung*. BoD–Books on Demand.

Meyersdorf, D. and A. Taghizadeh (1998). "Fab layout design methodology: Case of the 300 mm fabs". In: *Semiconductor international* 21.8, pp. 187–196.

Miltenburg, J. (2005). *Manufacturing strategy: how to formulate and implement a winning plan*. CRC Press.

Mönch, L. and M. Stehli (2006). "ManufAg: a multi-agent-system framework for production control of complex manufacturing systems". In: *Information Systems and e-Business Management* 4.2, pp. 159–185.

Monostori, L. (2014). “Cyber-physical production systems: Roots, expectations and R&D challenges”. In: *Procedia CIRP* 17.2014, pp. 9–13.

Nanotron (2017). “Company information”.

Niekisch, T. (2001). “Störungssystematikbestimmte Instandhaltung in einem Wafertransportsystem”. PhD thesis. Technische Universität Dresden.

Ostgathe, M. (2012). *System zur produktbasierten Steuerung von Abläufen in der auftragsbezogenen Fertigung und Montage*. Herbert Utz Verlag.

Puffer, W. (2007). “Technisch-ökonomische Effizienzbetrachtungen für die Halbleiterfertigung”. PhD thesis. Technische Universität München.

Reinhart, G., P. Engelhardt, F. Geiger, T. Philipp, W. Wahlster, D. Zühlke, and P. Stephan (2013). “PCyber-Physische Produktionssysteme. Produktivitäts-und Flexibilitäts-steigerung durch die Vernetzung intelligenter Systeme in der Fabrik”. In: *wt-online* 103.2, pp. 84–89.

Ropohl, G. (1979). “Eine Systemtheorie der Technik”. In: *München*.

Russell, S., P. Norvig, and A. Intelligence (1995). *Artificial Intelligence. A modern approach*. Eglnewood Cliffs: Prentice-Hall.

Scholz-Reiter, B., M. Freitag, H. Rekersbrink, B. L. Wenning, C. Gorldt, and W. Echelmeyer (2005). “Auf dem Weg zur Selbststeuerung in der Logistik-Grundlagenforschung und Praxisprojekte”. In: *Intelligente Logistikprozesse: Konzepte, Lösungen Erfahrungen - Begleitband zur 11. Magdeburger Logistiktagung*. Ed. by Logisch-Verlag. Magdeburg: Wäscher, G., pp. 166–180.

Scholz-Reiter, B. and H. Höhns (2006). “Selbststeuerung logistischer Prozesse mit Agentensystemen”. In: *Produktionsplanung und-steuerung*. Berlin Heidelberg: Springer, pp. 745–780.

Schuhmacher, J. and V. Hummel (2016). “Decentralized control of logistic processes in cyber-physical production systems at the example of ESB Logistics Learning Factory”. In: *Procedia CIRP* 54, pp. 19–24.

Seitz, K. F. and P. Nyhuis (2015). “Cyber-physical production systems combined with logistic models – a learning factory concept for an improved production planning and control”. In: *Procedia CIRP* 32, pp. 92–97.

Sonar, A., S. Shinde, and S. Teh (2013). “Automation: Key to Cycle Time Improvement in Semiconductor Manufacturing”. In: *IEEE/SEMI Advanced Semiconductor Manufacturing Conference 2013*. Saratoga Springs, NY.

Sternberg, R. J. and D. K. (Detterman (1986). *What is intelligence?: Contemporary viewpoints on its nature and definition*. Praeger Pub Text.

Wahlster, W. (2013). *Künstliche Intelligenz: Computer mit Augen, Ohren, Hand und Fuß – aber auch Verstand? Künstliche Intelligenz: Chance oder Risiko?* Tech. rep. Hamburger Akademievorlesungen.

Wang, L., M. Törngren, and M. Onori (2015). “Current status and advancement of cyber-physical systems in manufacturing”. In: *Journal of Manufacturing Systems* 37.2, pp. 517–527.

Windt, K. (2006). “Selbststeuerung intelligenter Objekte in der Logistik”. In: *Selbstorganisation: Ein Denksystem für Natur und Gesellschaft.* Ed. by B. Verlag. Köln Weimar: Vec, M., Hütt, M. T., Freund, A. M.

Winzker, M. (2008). *Elektronik für Entscheider: Grundwissen für Wirtschaft und Technik*. Springer-Verlag.

Wirtschaft und Energie), (für (2016). *Autonomik für Industrie 4.0. Ergebnisse.* Tech. rep.

Wooldridge, M. and N. R. Jennings (1995). “Intelligent agents: Theory and practice”. In: *The knowledge engineering review* 10.2, pp. 115–152.

Zbib, N., S. Raileanu, Y. Sallez, T. Berger, and D. Trentesaux (2008). *From passive products to intelligent products: the augmentation module concept. 5th International Conference on Digital Enterprise Technology*. Nantes, France.

Part III

Risk and Security Management

Cybersecurity in Ports: a Conceptual Approach

Jenna Ahokas[1], Tuomas Kiiski[1], Jarmo Malmsten[1], Lauri Ojala[1]

1 – Turku School of Economics at the University of Turku

As the world is becoming increasingly digitalized, the role of cybersecurity on society is mounting. Recent cyberattacks have showed the vulnerability of critical infrastructure, including ports. The objective is to describe how cybersecurity is perceived in ports, as preparedness and regulation for cyberthreats in ports appears inadequate. The study is a conceptual analysis built upon a comprehensive literature review. The results show that regardless of the growing awareness of the issue, much work needs to be done in order to mitigate the cyberthreats in ports. Situation calls for, among other things, adoption of industry standards and practical level coordination.

Cybersecurity in general has been a topical subject, while in the context of ports the theme has thus far been scantly studied. In addition, cybersecurity is currently not included in International Maritime Organization's safety and security Conventions relevant to port, such as ISPS or ISM. Hence this study is among the first openings in its field.

Keywords: Cybersecurity; Maritime Security; Critical Infrastructure; Ports

1 Introduction

The world is rapidly becoming digitalized and dependent on efficient communication systems. The activities, which traditionally have relied on paper documentation or manual processing, are now increasingly converted into electronic format, where data is stored in a digital environment called cyberspace (Goldby, 2008; Fitzgerald, et al., 2013). For business, the implications of these changes are massive by any standards, including improved data integrity, processing capacity and emergence of new business models (Boyes, Isbell and Luck, 2016). Some have even visioned a dawn of the fourth industrial revolution (Lasi, et al., 2014).

Downside of this development is that reliance on technology makes society susceptible to the functionality of systems (Urcioli, 2015; Carrapico and Barrinha, 2017). Along with natural disasters and terrorism, malicious acts by individuals through cyberspace on essential systems have been underlined as a potential threat to the society (Kapto, 2013). The motive behind cyberattacks are diverse, including excitement, money and political agendas (Ahokas and Kiiski, 2017). Assuring the resiliency of society against cyberattacks requires focusing on cybersecurity of critical infrastructure. Cybersecurity indicates the security of cyberspace in terms of access to, and control and storaging of data (Boyes, Isbell and Luck, 2016).

The concerns relating to cybersecurity have already materialized as the number of cyberattacks have shown a year-by-year increase, causing substantial financial losses to society in general and business in particular (Colesniuc, 2013). Hence cybersecurity has been identified as a top-level priority among policymakers, businesses, scholars and individual persons (Lewis, 2002). As a result, adoption of specific cybersecurity strategies have been initiated (ICC, 2015).

Ports are key nodes of global trade — approximately 80 per cent of world trade is transported by sea — and thus comprise an integral part of critical infrastructure (UNCTAD, 2016). In addition, ports hold substantial amounts of data, are involved in a large number of monetary transactions and stakeholders making them attractive objects for cyberattacks (CyberKeel, 2014; Jensen, 2015).

European Network and Information Security Agency (ENISA 2011) was one of the first to identify a lack of awareness of cybersecurity in maritime transport and ports. Despite substantial academic interest shown towards cybersecurity in general (Hult and Sivanesan, 2013) as well as maritime security (Germond, 2015), cybersecurity in ports seems far more uncharted an area (Ahokas and Kiiski, 2017).

Fresh empirical evidence from the Baltic Sea Region indicates that preparedness and regulation for cyberthreats in seaports appears inadequate (Ahokas and Laakso, 2017).

Concerns about cybersecurity have risen relatively recently, which is evidenced by the fact that cybersecurity is currently not mentioned in the International Maritime Organization IMO's safety and security Conventions relevant to ports, such as International Ship and Port Facility Security Code (ISPS) or International Safety Management Code (ISM). Apart from IMO's Interim guidelines on cybersecurity published in 2016 in Maritime Safety Committee's (MSC) Circular MSC.1/Circ.1526, there are no supranational guidelines how to tackle the issue.

However, IMO is making cyber risk management onboard ships mandatory as of 1 January 2021, as cited in Resolution MSC.428(98) on Maritime Cyber Risk Management in Safety Management Systems adopted in June 2017. The resolution states that an approved safety management system should take cyber risk management into account in accordance with the objectives and requirements of the ISM Code. Based on the recommendations in MSC.1/Circ.1526 Guidelines on maritime cyber risk management, the resolution confirms that existing risk management practices should be used to address the operational risks arising from the increased dependence on cyber enabled systems.

Thus, the gap of knowledge on cybersecurity in ports identified above merits further investigation on the topic. For this purpose, this paper reviews the key elements and aspects of cybersecurity with the focus on ports. A conceptual analysis is conducted through a comprehensive literature review aiming to address the following research question: ”How is cybersecurity perceived in ports?”

The paper is divided as follows: Section 2 contains a discussion regarding security from the perspective of ports. Section 3 elaborates the key concepts and issues related to cybersecurity. Section 4 provides insights on cybersecurity in ports. Section 5 sums up the results and draws conclusions.

2 Security Aspects in Ports

Risk, threat and security are essential concepts when scanning any business environment. By definition, a risk is a likelihood of an event with potentially either positive or negative consequences (Prezelj and Ziberna, 2013). According to Merriam-Webster dictionary a threat is ”an expression of intention to inflict evil, injury, or damage" (Merriam-Webster, 2017). Security is a concept with multidimensional meanings (Brooks, 2010), which is often addressing intentional threats in contrast to ones with accidental or natural origin (Craigen, Diakun-Thibault, and Purse, 2014). A difference between risk and security is that the latter involves also uncertainty (Marlow, 2010).

Maritime community, with its operating field encompassing around the globe, is susceptible to various types of threats. This turns the focus on maritime security, a concept of which has recently gained buzzword status among the policymakers (Bueger, 2015). Maritime security can be seen either as a state of security within the maritime domain or as a vehicle to mitigate risk of threats, for example, terrorism, piracy or smuggling, taking place not only on traditional sea or port locations, but also along the entire supply chain (Helmick, 2008; Germond, 2015).

Characteristics of a port make it challenging object from the security perspective. A port is a complex and multipart organization with institutions and functions crossing multiple layers (Baltazar and Brooks, 2007). A port usually consists of a port authority, port superstructure, for example cranes and conveyors, and infrastructure, loading and unloading operations, storage facilities, and intra-port operations (Brooks and Cullinane, 2007; Meersman and Van de Voorde, 2010).

From the national security perspective, ports, together with energy systems, transport infrastructure, health industry, and water supply facilities, comprise critical infrastructure (Ho and Ho, 2006; Prezelj and Ziberna, 2013). Critical infrastructure refers to facilities, networks, and assets, which are essential in terms of citizens' health, safety, security, and economic well-being as well as effective functioning of society (Carrapico and Barrinha, 2017).

Typical threats of ports include, but are not limited to, financial losses, theft of cargo or information, and strikes or system malfunctions that can compromise the operations of a port (Ho and Ho, 2006; Loh and Thai, 2015). Moreover, in light of the recent surge of activity, threat of terrorism should not be neglected. One scenario suggests that terrorist may target or use ships at sea or in ports as weapon to attack passengers and personnel of ports (Eski, 2011). Owing to technological development, a new kind of threats have emerged as digitalization has enabled threats coming through cyberspace to become reality (Rittinghouse and Hancock, 2003; Geers, 2009; Miron and Muita, 2014).

Port security related policymaking is traditionally driven by global shocks. For example, repercussions of 9/11 terror attacks led to global adoption of IMO's ISPS Code. The ISPS aims to enhance maritime security both on ships and in ports (Pinto and Talley, 2006; Thai and Grewal, 2007). Adoption of such initiatives comes with a price, of which are usually put on shipper's account (Dekker and Stevens, 2007). However, policies pursued by the major players persists fragmented (Papa, 2013). For example, the USA adopted national policies such as Container Security Initiative, which differs from global standards (Marlow, 2010).

3 Key Concepts and Issues Related to Cybersecurity

The literature behind cyber-related issues is arguably embedded with various cyber-prefixed concepts, of which are often used interchangeably (Bayuk, et al., 2012). In order to make clarity in this complex field, the first part the Section provides a conceptual image of the process involving concepts related to cybersecurity. The remainder of the Section contains elaborate definitions of the concepts in question.

3.1 Conceptual Illustration

Figure 1 provides a simplified process description of the relevant concepts and their mutual relationships. In a nutshell, conceptual description of the role of cybersecurity (C) is as follows. All action is taking place in cyberspace (A), where system (B; here e.g. the IT systems of a port community) is located. It is protected by cybersecurity (C). System vulnerabilities (D) together with existing cyberthreats (F) and the level of cybersecurity (C) comprise the level of cyberrisk (E) at any given time. In case cybersecurity (C) is not at an adequate level, cyberrisk (E) may materialize through a cyberattack (G), which targets the system (B) through an identified vulnerability (D). In practice, a cyberattack (G) can be considered as a materialized cyberthreat (F), which contains also specific technical methods to inflict damage.

3.2 Definitions

According to Rantapelkonen and Kantola (2013, p.25) cyberspace is "the collection of computing devices connected by networks, in which electronic information is stored and utilized, and communication takes place".

Merriam-Webster dictionary defines cybersecurity as ”measures taken to protect a computer or computer system (as on the Internet) against unauthorized access or attack” (Merriam-Webster, 2017). In other words, the objective of cybersecurity is a stable condition, where cyberspace is trusted and protected. At this point, there is also sufficient capacity to proactively control and sustain cyberthreats (Ministry of Defence of Finland, 2013; Limnéll, Majewski and Salminen, 2015).

Vulnerability refers to a feature or weakness of a computer or data system’s design, integration, and maintenance (Maurushat, 2013). Vulnerability can either be direct such as weak passwords that lead to unauthorized access, or indirect such as the absence of network segregation (IMO, 2016a). Spotting the vulnerabilities requires great precision as it is estimated that over 90 per cent of attackers are familiar with the vulnerabilities of their targets (Afful-Dadzie and Allen, 2014; Loukas, 2015). According to Maurushat (2013) vulnerabilities can be divided into three categories: 1) known vulnerability, 2) zero-day attack, and 3) future threat.

A known vulnerability is noticed in public through some form of communication such as publication, and refers to failure of existing paradigms for recognizing, reacting to or mitigating vulnerabilities. A zero-day attack refers to utilization of a security vulnerability on the same day, when it becomes generally known. A future threat means a condition that could end in harm as a consequence of a formerly unknown security vulnerability. Vulnerabilities are increasing e.g. due to i) shift of society towards on ubiquitous and automated computing environment; and ii) increased utilization of the Internet (Lewis, 2002).

Cyberrisk refers to a variety of different sources of risk affecting the information and technology assets of a firm (Biener, Eling and Wirfs, 2015). In more detail, realized risks may result financial losses, disruption or damage to the reputation of an organization from some sort of failure of its information technology systems (IRM, 2014).

The growth of digitalization has entailed increase in frequency, sophistication and scope of cyberthreats (Chertoff, 2008). A cyberthreat refers to a malicious attempt in cyberspace, which aims to damage or interrupt a computer network or system (Boyes, Isbell and Luck, 2016). Five basic types of cyberthreats are hacktivism, cybercriminality, cyberespionage, cyberterrorism and cyberwar (table 1). Each of them has their individual features relating to actors involved, as well as motivations and objectives behind actions.

Hacktivism refers to operations in cyberspace that make use of various hacking techniques to invade into web pages and on computers, and create pressure

Table 1: Types and elements of cyberthreats

Cyberthreats	Actors	Motivations	Objectives
Hacktivism	Hacktivists Hackers Individuals	Egoism Political Reputation	Attention Disruptions Knowledge
Cybercriminality	Individuals Industrial spies Organized crime	Economical Informational	Cargo Digital assets Organizational data
Cyberespionage	Industrial spies Governments Organized crime	Ideological Informational Political	Digital assets Knowledge Organizational data
Cyberterrorism	Governments Terrorists	Ideological Political Religious Social	Disruptions National institutions Critical Infrastructure
Cyberwar	Governments Terrorists	Egoism Political Religious Social	Military National Critical

on a certain object (Limnéll, Majewski and Salminen, 2015; Boyes, Isbell and Luck, 2016). A hacker uses own quick programming skills for invading into a computer network file and seeks recognition for his/her technological capabilities (Christou, 2016). Hackers can be divided into three different groups (Rittinghouse and Hancock, 2003; Kapto, 2013):

1. White-hat hacker aims to promote security with his/her actions
2. Grey-hat hacker, often with criminal background, seeks gaps and vulnerabilities
3. Black-hat hackers, i.e. a hacktivist, has criminal intentions

Cybercriminality refers to criminal activities that involve computer and information systems either as a primary tool or as a primary target (Christou, 2016; Carrapico and Barrinha, 2017). The aim is to gain financial benefits or to inflict personally motivated harm such as revenge or bullying (Gross, Canetti and Vashdi, 2017). The economic benefit of cybercriminality can include criminal damage, robbery of cargo, or identity thefts (European Commission, 2013; Boyes, Isbell and Luck, 2016). Cybercriminality can be divided into four categories (Limnéll, Majewski and Salminen, 2015; Luppicini, 2014):

1. Actions endangering confidentiality, integrity and availability of data and systems
2. Forgery or identity thefts
3. Illicit gambling or spreading false information
4. Copyright or brand violations

Cyberespionage refers to illegal access to secret and delicate information such as company strategy, private information, or intellectual capital, and it aims for getting competitive advantage (Rittinghouse and Hancock, 2003; Boyes, Isbell and Luck, 2016). Five different losses can be seen as a consequences of cyberespionage (Platt, 2011; Fitzpatrick and Dilullo, 2015):

1. Loss of intellectual property, business and customer information
2. Extra costs due to interrupted business plans and competitive exercises
3. Loss of profits and efficiency
4. Damage to company reputation

5. Increased IT related security costs

Cyberterrorism is defined by Limnéll, Majewski and Salminen (2015, p.131) as ”a deliberate politically motivated attack against information, computer systems, computer software, and databases in the form of a violent invasion by international groups or secret agents”. Cyberterrorist is an individual, who is specialized in hacking into computer systems and is competent in organizing individual cyberattacks on global networks (Kapto, 2013).

Cyberwar is a part of modern information war between nations, during which cyberattacks are made against opponents computer networks, which are relevant from the military perspective (Lewis, 2002; Ministry of Defence of Finland, 2011; Kapto, 2013). Cyberwar employs malicious software and viruses to disable military targets (Gross, Canetti and Vashdi, 2017).

In case cyberrisks are realized, a cyberattack will take place, which has the basic elements of cyberthreats in relation to actors, motivations and objectives. The exact methods used by cyberattackers vary, while the most common ones are phishing, malicious software and Denial-of-Service attack. (Colesniuc, 2013; CyberEdge Group, 2016). Phishing is an attempt to gain discrete information by imitating a reputable enterprise or person in e-mail or other communication channel. Malicious software or malware is a harmful program to steal, encrypt, delete or change data, hijack or monitor users of target computer (Kendrick, 2010). A Denial-of-Service (DoS) attack is an attempt to overtake a network by blocking it with huge amount of communication (Fok, 2015).

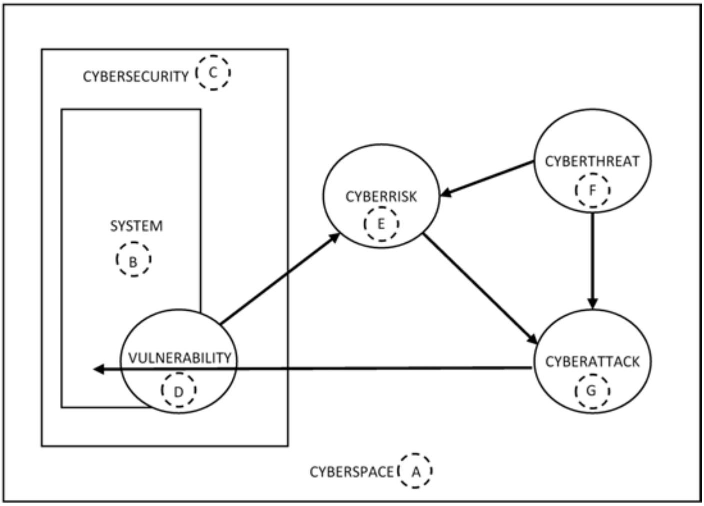

Figure 1: Simplified process chart of concepts related to cybersecurity

4 Cybersecurity in Ports

ENISA's study in 2011 on cybersecurity in maritime transport and ports identified a clear lack of awareness on cybersecurity issues (ENISA, 2011). However, this has not resulted in any European-wide strategy or coordinated action on the topic. As mentioned in Section 2, critical infrastructure, including ports, constitutes a likely target for cyberattacks given its significance on the functionality of societies. In addition, what makes ports particularly vulnerable to cyberthreats relates to their basic characteristics: dependency of data systems, handling massive volumes of cargo or passengers , high monetary values, immense number of transactions, numerous stakeholders involved, as well as non-transparent ownership of goods end equipment (see e.g. Jensen, 2015). The geographical location may also be influential as cyberattackers have been noted to target operators inside ports, where the level of preparation tends to be low (Miron and Muita, 2014).

Potential consequences of cyberattacks against ports can be harmful in many ways. The most common ones are scenarios, where cyberattackers gain access to one or more of the following: i) overtake control of a ship, ii) shut down the entire port, iii) delete or alter operational data, or iv) access to delicate information (CyberKeel, 2014).

In response to a growing pressure for countermeasures against cyberthreats, policymakers throughout the world have started the adoption of multilevel general cybersecurity strategies. Examples of these is the United Kingdom's National Cyber Security Strategy 2016–2021 (UK, 2016) at a national level, and the Cyber security strategy of European Union: an Open, Safe and Secure Cyberspace (European Commission, 2013) at a supranational level.

Similarly, work has begun among maritime authorities and international organizations to develop strategies and standards for port facilities and ships against cyberthreats. However, there are some challenges in this process. When designing maritime specific guidelines, the globalized nature of the business and large number of stakeholders set requirements for policy development. For example, operations of a large container shipping company can easily involve over 100 countries, and its fleet size be measured in several hundreds of vessels (Jensen, 2015). Global coordination and standardization of practices are essential elements in this regard. So far none of the maritime specific guidelines are not mandatory by nature, which may hinder the adoption process.

In 2015, the United States Coast Guard (2015) introduced its Cyber strategy (for critical maritime infrastructure). The Institution of Engineering and Technology (IET) introduced in 2016 the Code of Practice (Boyes, Isbell and Luck, 2016).

In 2016, the Baltic and International Maritime Council (BIMCO), the International Chamber of Shipping (ICS), INTERCARGO, INTERTANKO and the Cruise Lines International Association (CLIA) published ”Guidelines on Cyber Security Onboard Ships” (BIMCO, et al., 2016). The guidelines introduced a six-step approach, which is dedicated to cybersecurity and cyberthreats:

1. Identification of external and internal cyberthreats
2. Identification of vulnerabilities
3. Assessment of risk exposure
4. Development of protection and detection measure
5. Establishment of contingency plan
6. Response to cybersecurity incidents

In 2016, IMO published the ”Interim Guidelines on Maritime Cyber Risk Management”, which underlines that cyberrisk management should be complementary to existing security and safety risk management requirements, like ISM and ISPS Codes (IMO, 2016a). The objective of IMO's guidelines is to keep cyberrisks at a reasonable level by using multilevel approach that involves all relevant port actors (IMO, 2016a).

By and large, the number of reported cyberattacks against ports has remained on a very low level thus far. The only case, which has received wider attention, was the attack against port of Antwerp in late-2013 (Boyes, Isbell and Luck, 2016). The exact reasons behind absence of attacks can only be speculated. Similarly, the number of attempts is fairly uncertain given that they may not be reported or noticed. It should be remembered that the security situation is constantly evolving — what was adequate yesterday may not hold today.

There is very limited amount of publicly available information about contemporary cybersecurity related practices in ports, which is presumably due to discretionary nature of the subject. However, initial empirical evidence from the Baltic Sea Region indicate that neither ports nor regulation seem to be well prepared to cyberthreats (Ahokas and Laakso, 2017).

Moreover, it appears that other maritime industry sectors are not neither that well prepared against cyberthreats. In mid-2017, there was a cyberattack against the world's largest shipping line, Maersk, which temporarily crippled the entire company (Knowsler, 2017). The episode has explicitly showed that there is still room for improvement in this sector as well.

The notion of ports lesser role in terms of cybersecurity considerations receives support when looking at academic literature, as the number of articles concerning cybersecurity in ports is scarce. In addition, the topic appears recent, i.e. published after 2011. Apart from two peer-reviewed journal articles by Kouwenhoven (2014) and Jones (2015), other dedicated reports are predominantly industry, policy or consultancy papers (Ahokas and Kiiski, 2017). The topic's novelty is convergent with the body of literature, while the scarcity observation is contrasting given the reported influx of studies covering cybersecurity and maritime security in general (Germond, 2008; Jensen, 2015).

5 Results and Conclusions

The recent growth of cyberattacks and subsequent increased awareness of cybersecurity, in which ports appeared to be somewhat neglected, provided the ultimate inspirations for this paper. A conceptual analysis, which was based on comprehensive literature review, was conducted. Objective of the paper was to describe cybersecurity in ports by answering to specific research question: "How is cybersecurity perceived in ports?" This was approached by first establishing port's dual role in security as being part of both maritime and national security considerations. After this, the relevant terminology and concepts related to cybersecurity were scrutinized. Finally, state-of-the-art situations about cybersecurity in ports were mapped.

The results show that regardless of the growing awareness of the issues, much work needs to be done in order to mitigate the cyberthreats in ports. The matter is both novel and of great urgency as cyberattacks are becoming more common with pervasive impacts on society. Maritime sector and ports in particular are no exception in this regard as recent attacks against Maersk and port of Antwerp have showed.

There is limited amount of information available about the contemporary cybersecurity related practices in ports, which presumably is due to discretionary nature of the subject. However, there are indications suggesting that the ports current level of preparation and regulations are not adequate.

Over the past five years, policymakers and other stakeholders have become actively engaged in cyberthreats by adopting cybersecurity strategies and guidelines, for example, IMO (2016a) and BIMCO, et al. (2016). However, mandatory global standards are yet to be introduced, which, among other things, could expedite the adoption process. Owing to the global scale and large number of parties involved, coordinated efforts are needed to ensure adoption of adequate practices and regulations throughout the industry. This supports Helmick's (2008) call for extensive cybersecurity framework. Here, IMO's Resolution adopted in June 2017 to make cyber risk management onboard ships mandatory as of 1 January 2021 is a significant, yet belated step ahead. Similar steps for seaports are still pending.

Unlike popular research streams of maritime security and cybersecurity in general, the port environment in a cyber context appears to have received scant exposure. Only few journal papers appear to have dealt with the topic, while the majority of publications consist of consultancy or policy related papers.

The terminology behind cybersecurity appears far from being harmonized as the use of various concepts with different meanings is common (see also IMO, 2016b). This finding supports previous arguments by Craigen, Diakun-Thibault and Purse (2014) and Hult and Sivanesan (2013). Especially the relationship between cyberthreat and cyberattack is a cumbersome (Kadivar, 2014; Loukas, 2015). In order to provide input to this issue, a conceptual map was introduced that delineates the relationships between different concepts.

This paper contains limitations that needs to be taken into consideration. The major limitation compounds from the novelty of the topic as there is only limited amount of publications and empirical data available. Future research should study port cybersecurity strategies in more detail, for example, by establishing a suitable typology and/or a taxonomy on these preparation plans. In addition, more information is needed about how these strategies have been implemented empirically and how effective they are in terms of mitigating cyberthreats.

References

Afful-Dadzie, A. and T. T. Allen (2014). "Data-Driven Cyber-Vulnerability Maintenance Policies". In: *Journal of Quality Technology* 46.3, pp. 234–250.

Ahokas, I. and K. Laakso (2017). *Deplhi study on safety and security in the Baltic Sea Region ports*. URL: https://blogit.utu.fi/hazard/.

Ahokas, J. and T. Kiiski (2017). *Cybersecurity in ports*.

Baltazar, R. and M. R. Brooks (2007). "Port Governance, Devolution and the Matching Framework: a Configuration Theory Approach". In: *Devolution, Port Governance and Port Performance*. Ed. by M. R. Brooks and K. Cullinane. London: Elsevier, pp. 379–403.

Baltic and International Maritime Council (BIMCO), International Chamber of Shipping (ICS), INTERCARGO, INTERTANKO, and Cruise Lines International Association (CLIA) (2016). *The Guidelines on Cyber Security Onboard Ships. Version 1.1.* Bagsvaerd.

Bayuk, J. L., J. Healey, P. Rohmeyer, M. H. Sachs, J. Schmidt, and J. Weiss (2012). *Cyber Security Policy Guidebook*. New Jersey: Wiley.

Biener, C., M. Eling, and J. H. Wirfs (2015). "Insurability of Cyber Risk: an Empirical Analysis". In: *The Geneva Papers* 40, pp. 131–158.

Boyes, H., R. Isbell, and A. Luck (2016). *Code of Practice: Cyber Security for Ports and Port Systems*. Stevenage.

Brooks, D. J. (2010). "What is Security: Definition through knowledge categorization". In: *Security Journal* 23.3, pp. 225–239.

Brooks, M. R. and K. Cullinane (2007). "Governance Models Defined". In: *Devolution, Port Governance and Port Performance*. Ed. by M. R. Brooks and K. Cullinane. London: Elsevier, pp. 405–435.

Bueger, C. (2015). "What is maritime security?" In: *Marine Policy* 53, pp. 159–164.

Carrapico, H. and A. Barrinha (2017). "The EU as a Coherent (Cyber)Security Actor?" In: *Journal of Common Market Studies*, pp. 1–19.

Chertoff, M. (2008). "The cybersecurity challenge". In: *Regulation and Governance* 2.4, pp. 480–484.

Colesniuc, D. (2013). "Cyberspace and Critical Information Infrastructure". In: *Informatica Economica* 17.4, pp. 123–132.

Commerce (ICC), I. C. of (2015). *Cyber Security Guide for Business*. Paris.

Craigen, D., N. Diakun-Thibault, and R. Purse (2014). "Defining Cybersecurity". In: *Technology Innovation Management Review* 4.10, pp. 13–21.

CyberKeel (2014). *Maritime Cyber-Risks*. Copenhagen.

Cybersecurity in the European Union: Resielience and Adaptability in Governance Policy (2016). Hampshire: Palgrave Macmillan.

Cybersecurity Strategy of the European Union: An Open, Safe and Secure Cyberspace (2013). URL: https://ec.europa.eu/digital-single-market/en/news/eu-cybersecurity-plan-protect-open-internet-and-online-freedom-and-opportunity-cyber-security.

Defense, M. of (2011). *Security Strategy for Society - Government Resolution 16.12.2010*. Helsinki: Ministry of Defense of Finland.

Defense, M. of (2013). *Finland's Cyber Security Strategy - Government Resolution 24.1.2013*. Helsinki: Ministry of Defense of Finland.

Dekker, S. and H. Stevens (2007). "Maritime security in the European Union — empirical findings on financial implications for port facilities". In: *Maritime Policy & Management* 34.5, pp. 485–499.

Eski, Y. (2011). ""Port of Call": Towards a criminology of port security". In: *Criminology & Criminal Justice* 11.5, pp. 415–431.

Fitzgerald, M., N. Kruschwitz, D. Bonnet, and M. Welch (2013). *Embracing Digital Technology: A New Strategic Imperative*. 2, pp. 1–12.

Fitzpatrick, W. M. and S. A. Dilullo (2015). “Cyber Espionage and the S.P.I.E.S. Taxonomy”. In: *Competition Forum* 13.2, pp. 307–336.

Fok, E. (2015). “Cyber Security Challenges: Protecting Your Transportation Management Center”. In: *Institution of Transportation Engineers Journal* 85.2, pp. 32–36.

Geers, K. (2009). “The Cyber Threat to National Critical Infrastructures: Beyond Theory”. In: *Information Security Journal: A Global Perspective* 18.1, pp. 1–7.

Germond, B. (2015). “The geopolitical dimension of maritime security”. In: *Marine Policy* 54, pp. 137–142.

Goldby, M. (2008). “Electronic bills of lading and central registeries: what is holding back progress?” In: *Information & Communications Technology Law* 17.2, pp. 125–149.

Gross, M. L., D. Canetti, and D. R. Vashdi (2017). “Cyberterrorism: its effects on psychological well-being, public confidence and political attitudes”. In: *Journal Of Cybersecurity* 3.1, pp. 49–58.

Group, C. (2016). *2016 Cyberthreat Defense Report - North America, Europe, Asia Pacific, and Latin America*. Annapolis.

Helmick, J. S. (2008). “Port and maritime security: A research perspective”. In: *Journal of Transportation Security* 1.1, pp. 15–28.

Ho, M. W. and K. H. (Ho (2006). “Risk Management in Large Physical Infrastructure Investments: The Context of Seaport Infrastructure Development and Investment”. In: *Maritime Economics & Logistics* 8.2, pp. 140–168.

Hult, F. and G. Sivanesan (2013). “Introducing cyber”. In: *Journal of Business Continuity & Emergency Planning* 7.2, pp. 97–102.

International Maritime Organization (IMO) (2016a). *IMO Multilingual Glossary on Cyberterms*. London.

International Maritime Organization (IMO) (2016b). *Interim Guidelines on Maritime Cyber Risk Management*. London.

Jensen, L. (2015). “Challenges in Maritime Cyber-Resilience”. In: *Technology Innovation Management Review* 5.4, pp. 35–39.

Jones, S. (2015). “Addressing cyber security risks at ports and terminals”. In: *Port Technology International Journal* 62.

Kadivar, M. (2014). “Cyber-Attack Attributes”. In: *Technology Innovation Management Review* 4.11, pp. 22–27.

Kapto, A. S. (2013). “Cyberwarfare: Genesis and Doctrinal Outlines”. In: *Herald of the Russian Academy of Science* 83.4, pp. 357–364.

Kendrick, R. (2010). *Cyber Risks for Business Professionals: A Management Guide*. Cambridgeshire: IT Governance Publishing.

Knowsler, G. (2017). *Maersk cyber attack forces carrier to put cargo bookings on hold*. URL: http://fairplay.ihs.com/article/4288541/maersk-cyber-attack-forces-carrier-to-put-cargo-bookings-on-hold.

Kouwenhoven, N. (2014). “The implications and threats of cyber security for ports”. In: *Port Technology International Journal* 61.

Lasi, H., P. Fettke, H.-G. Kemper, T. Feld, and M. Hoffmann (2014). “Industry 4.0”. In: *Business & Information Systems Engineering* 6.4, pp. 239–242.

Lewis, J. A. (2002). “Assessing the Risks of Cyber Terrorism, Cyber War and Other Cyber Threats”. In:

Limnéll, J., K. Majewski, and M. Salminen (2015). *Cyber Security for Decision Makers*. Docendo.

Loh, H. S. and V. V. Thai (2015). “Management of disruptions by seaports: preliminary findings”. In: *Asia Pacific Journal of Marketing and Logistics* 27.1, pp. 146–162.

Loukas, G. (2015). *Cyber-Physical Attacks: A Growing Invisible Threat*. Oxford: Elsevier Science.

Luppicini, R. (2014). “Illuminating the Dark Side of the Internet with Actor-Network Theory: An Integrative Review of Current Cybercrime Research”. In: *Global Media Journal - Canadian Edition* 7.1, pp. 35–49.

Marlow, P. B. (2010). “Maritime security and update of key issues”. In: *Maritime Policy & Management* 37.7.

Maurushat, A. (2013). *Disclosure of Security Vulnerabilities: Legal and Ethical Issues*. London: Springer.

Meersman, H. and E. Van de Voorde (2010). “Port Management, Operation and Competition: a Focus on North Europe”. In: *The handbook of Maritime Economics and Business*. Ed. by C. T. Grammenos. London: Lloyd’s List, pp. 891–906.

Merriam-Webster Dictionary (2017). URL: https://www.merriam-webster.com/.

Miron, W. and K. Muita (2014). “Cybersecurity Capability Maturity Models for Providers of Critical Infrastructure”. In: *Technology Innovation Management Review* 4.10, pp. 33–39.

Papa, P. (2013). “US and EU strategies for maritime transport security: A comparative perspective”. In: *Transport Policy* 28, pp. 75–85.

Pinto, C. A. and W. K. Talley (2006). “The Security Incident Cycle of Ports”. In: *Maritime Economics & Logistics* 8.3, pp. 267–286.

Platt, V. (2011). “Still the fire-proof house? An analysis of Canada’s cyber security strategy”. In: *International Journal: Canada’s Journal of Global Policy* 67.1, pp. 155–167.

Prezelj, I. and A. Ziberna (2013). “Consequence-, time- and interdependency-based risk assessment in the field of critical infrastructure”. In: *Risk management* 15.2, pp. 100–131.

Rantapelkonen, J. and H. Kantola (2013). “Insights into Cyberspace, Cyber Security, and Cyberwar in the Nordic Countries”. In: *The Fog of Cyber Defense*. Ed. by J. Rantapelkonen and M. Salminen. Helsinki: National Defense University, pp. 24–36.

Risk Management (IRM)l, I. of (2014). *Cyber Risk: Executive Summary*. London.

Rittinghouse, J. and W. M. Hancock (2003). *Cybersecurity Operations Handbook*. London: Elsevier Digital Press.

Thai, V. v. and D. Grewal (2007). “The Maritime Security Management System: Perceptions of the International Shipping Community”. In: *Maritime Economics & Logistics* 9.2, pp. 119–137.

Trade, U. N. C. on and Development (2016). *Review of Maritime Transport 2016*. New York: United Nations Publication.

United Kingdom, H. G. (2016). *National Cyber Security Strategy 2016-2021*. London.

Urcioli, L. (2015). “Cyber-Resilience: A Strategic Approach for Supply Chain Management”. In: *Technology Innovation Management Review* 5.4, pp. 13–18.

Smart Supply Chain Risk Management - A Conceptual Framework

Florian Schlüter[1], Michael Henke[1]

1 – Technical University of Dortmund

Screening existing literature on Supply Chain Risk Management (SCRM) shows that only sporadic attention is paid on real data driven SCRM. Most tools and approaches lead to an expert knowledge based SCRM. Due to the arising topic of digitalization in supply chains, leading to Industry 4.0 (I4.0), there is huge potential in building a data driven, smart SCRM. To speed up research in this direction it is worthwhile to define a new research framework giving direction. To create a consistent framework and define smart SCRM in more detail a literature review will take place to select appropriate dimensions like SCRM phases, readiness stages of Digitalization/ I4.0 and SC perspectives describing the degree of SC collaboration. Afterwards the SCRM and I4.0 dimensions will be put into focus describing what impact I4.0 will have on SCRM leading to future requirements. The new framework serves as a basis for future SSCRM research. It helps to categorize research projects through multiple dimensions and to identify potential research gaps. The developed SSCRM requirements framework is a practical tool guiding the requirement specification when designing a company specific SSCRM system.

Keywords: Supply Chain Risk Management; Industry 4.0; Digitalization

1 Introduction

There are many example cases in the literature, like Ericsson (Chopra and Sodhi, 2004; Norrman and Jansson, 2004), Toyota (Pettit, Crocton and Fiksel, 2013) and Land Rover (Tang and Tomlin, 2008), which show that a supply chain disruption and a resulting glitch can have serious cascading effects on all supply chain members and their performance.

To lower the impact of such glitches firms usually establish a supply chain risk management (SCRM) which became a critical supply chain management discipline in the past due to the increasing number of events causing supply chain disruptions (Hillman and Keltz, 2007). In the past usually historical company and external data are used in the traditional SCRM concept (Güller, et al., 2015). The limitation of these practices is that information is not available timely enough and they don’t provide a real-time view of the entire supply chain operations (Güller, et al., 2015). Faisal, Banwet and Shankar (2006) have empirically shown the benefit of information sharing of supply chain members to understand the different risks which could have an impact on the supply chain. While supply chain risk information has been identified as crucial, the importance of a firm’s information processing capability to its SCRM effort has received little attention in the literature (Fan, et al., 2016). A system which processes SC risk (SCR) information would help firms to respond in a timely manner (Fan, et al., 2017) and enables recognition, analysis and assessment of negative trends to manage risks inside and outside of the SC (Zweig, et al., 2015).

Due to the arising topic of digitalization in supply chains (Pfohl, Yahsi and Kurnaz, 2015; Kersten, et al., 2016) there is huge potential in building a data driven, smart SCRM (Schröder, Indorf and Kersten, 2014). Available real-time information and data-processing tools bring new opportunities for companies to react more quickly to changing conditions within the supply chain (Güller, et al., 2015). The new principles and components of Industry 4.0 (I4.0) (e.g. Hermann, Pentek and Otto, 2016; Siepmann, 2016a; 2016b) lead also to a SCRM based on different principles compared to classical SCRM (Schröder, Indorf and Kersten, 2014; Schlüter, Diedrich and Güller, 2017). Therefore and to speed up research it is worthwhile to define Smart Supply Chain Risk Management (SSCRM) as a sub-research field within the field of SCRM and to come up with a new research framework giving direction.

The purpose of this paper is to create a consistent framework based on existing literature, serving as a basis for future SSCRM research. It helps to categorize research projects to identify potential research gaps. Afterwards a guiding design instrument for individual SSCRM requirement definitions will be derived. This leads to a practical tool supporting the design process for a company specific SSCRM system.

After a research overview in section 2 the research questions will be defined. In section 3 the framework will be developed and SSCRM will be defined in more detail in section 4. The paper closes in section 5 with a conclusion, an outlook for further research and managerial implications.

2 Research Overview

For an appropriate definition of a SSCRM research framework it is necessary to define SCRM and give insights about digitalization and related concepts. The section ends with an overview about related research and the research questions which will be answered throughout the rest of the paper.

2.1 Supply Chain Risk Management

SCRM can be seen as an emerging critical and cross-functional discipline between Supply Chain Management (SCM), corporate strategic management and Enterprise Risk Management (ERM) (Hillman and Keltz, 2007; Zsidisin and Ritchie, 2009). In their literature review, Ho, et al. (2015) stated that the proposed definitions of SCRM in the literature usually focus on specific elements of SCRM and do not span the SCRM processes completely or differ in their SCRM methods and types of events. Given this, the authors also follow Ho, et al. (2015) in their definition of SCRM as: “an inter-organizational collaborative endeavor utilizing quantitative and qualitative risk management methodologies to identify, evaluate, mitigate and monitor unexpected macro and micro level events or conditions, which might adversely impact any part of a supply chain”.

2.2 Digitalization and related concepts

A digitalized SC makes potential risks visible, allows companies to monitor material flows in real time and to develop future plans (Goh, et al., 2013). The integration of Cyber-Physical-Systems (CPS) in existing or new supply chain processes leads to a convergence of the physical world and the virtual world (Wan, Cai and Zhou, 2015) and are the foundation of an I4.0 (Bischoff, et al., 2015). CPS are physical objects, equipped with embedded systems, sensors and actuators adding intelligence and the ability for self-control, cross-linking with other CPS and for interaction with their environment (Bischoff, et al., 2015). Beside the term Digitalization there are other definitions in the literature with a similar meaning, like Industrial Internet, Internet of Things, Integrated Industry, Smart Industry, Smart Manufacturing and I4.0 (Hermann, Pentek and Otto, 2016). Especially the term Industry 4.0 or Industrie 4.0 is widely used in German speaking literature and slowly makes its way into Anglo-Saxon literature (e.g. Wan, Cai and Zhou, 2015 or Qin, Liu and Grosvenor, 2016). The main characteristic of the I4.0 is autonomization based on cross-linked systems which communicate with each other via Internet (Roth, 2016). For this paper the term Digitalization is defined as a necessary action on the road to I4.0 and will be used synonymously at some points. More information about I4.0, Digitalization and its components can be found in the literature (Bauernhansl, ten Hompel and Vogel-Heuser, 2014; Bischoff, et al., 2015; ten Hompel and Henke, 2017).

2.3 Smart Supply Chain Risk Management

The integration of CPS into supply chains leads to a smart supply chain management, which combines multiple independent data analytics models, historical data repositories, and real-time data streams (Wang and Ranjan, 2015). Through this embedded intelligence, supply chain management moves from supporting decisions to delegating them and, ultimately, to predicting which decisions need to be made (Butner, 2010). The main drivers for the digitalization of supply chain processes are typically an increase in flexibility and reaction rate of industrial/logistic systems (ten Hompel and Henke, 2017). Another perspective is to improve the supply chain robustness by using this available data from digitalized supply chain processes and CPS in SCRM, leading to a smart SCRM. Making the supply chain smarter from a risk management perspective can be described as "SCRM digitalization", thus as: "the integration of technology (sensors, actors, connectivity, analytics) along supply chain processes to improve supply chain risk identification, analysis, assessment, mitigation and monitoring through processing real time supply chain risk information – which comprises supply chain risk information sharing and analysis" (Schlüter, Diedrich and Güller, 2017).

2.4 Existing work

In the literature various works for both SCRM and Digitalization can be found which try to guide researchers as well as practitioners in their effort to find and define new research gaps and projects.

In SCRM most of this work is done over the past years via structured literature reviews (SLRs), which are usually based on statistical analysis of the existing literature at the time of release. They are either focusing more on specific SCRM sub-topics (e.g. Tang and Musa, 2011; Fahimnia, et al., 2015; Heckmann, Comes and Nickel, 2015; Kilubi and Haasis, 2016) to show there are specific research gaps or they are more generalized to show multiple research gaps in different sub-topics of SCRM (e.g. Jüttner, Peck and Christopher, 2003; Ritchie, 2007; Singhal, Agarwal and Mittal, 2011; Ho, et al., 2015). Also using the same steps, Schlüter, Diedrich and Güller (2017) performed a literature review to identify literature mentioning how digitalization and the usage of data driven tools will somehow affect SCRM in the near future. While doing so these publications are not focusing on creating a SSCRM, their main purpose is to bring new/better tools into the classic SCRM procedure. A similar publication comes from Schröder, Indorf and Kersten (2014) who postulate briefly how I4.0 will change the steps of SCRM and they propose new risks arising in the I4.0. The above mentioned literature usually focuses on different variations of a SCRM framework, describing the process of SCRM while none attention is paid defining a research framework to structure work in the field of SCRM. To the authors knowledge only the three-dimensional framework by Lindroth and Norrman (2001) can be used to structure work within the field of SCRM. The framework has been further developed and extended by Norrman and Lindroth (2004).

Within the field of Digitalization some framework approaches to cluster current and future research are available. Those are usually focusing on I4.0 in general. Pfohl, Yahsi and Kurnaz (2015) designed a matrix to categorize research within four research-fields, based on the two dimensions “Confirmatory Quantitative vs. Exploratory Qualitative” and “Analysis on management-level vs. Analysis on technology- and process-level”. To give direction for practitioners and researchers the “Dortmund Management-Model for Industry 4.0” by Henke, establishes and formalizes “work-clusters” for transforming value creating activities into the I4.0 (ten Hompel and Henke, 2017).

A recent publication of Lu (2017) gives insights about the development of publication numbers of I4.0 literature and the author has clustered 88 selected publications in categories like “Concepts and perspectives of Industry 4.0”, “Key technologies of Industry 4.0” or “Applications of Industry 4.0”.

Until now there is no known research framework available in the literature connecting SCRM and Digitalization into a SSCRM research framework, which helps to classify above mentioned research and to identify new research directions and helps to develop a guiding tool for developing company specific SSCRM requirements.

This leads to the following research questions:

RQ1: How does a research framework based on those dimensions look like?.

RQ2: What are appropriate fist definitions of SSCRM maturity steps and role definitions?

3 Developing a research framework

The advanced framework of Norrman and Lindroth (2004) serves as basis for the SSCRM.

In one dimension Norrman and Lindroth (2004) introduced five units of analysis in SCRM: single logistical activity within a company (single logistics); logistical activities of the whole company (company logistics); logistical activities between two companies (dyads logistics); logistical activities between companies linked to a chain (supply chain logistics) and logistical activities between companies linked to a network (supply chain network). These different scopes of SCM should be included to reflect the different levels of collaboration presented in the literature.

For the second dimension Norrman and Lindroth (2004) present four SCRM stages but they give no information on why these stages have been selected. Screening existing literature (see section 2) shows that there is a diverse understanding. For a comprehensive framework it is necessary to screen available literature about SCRM steps and build a SCRM procedure based on the findings. A research overview about paper explicitly describing models and frameworks of SCRM comes from Ponis and Ntalla (2016). de Oliveira, et al. (2017) performed a similar approach by screening 27 publications for SCRM steps and comparing them with the ISO 31000-SCRM procedure (see e.g. Curkovic, Scannel and Wagner, 2013). Based on their exhaustive literature review the following SCRM stages will be

Table 1: Industry 4.0 Maturity Stages (Schuh, et al., 2017)

Maturity stage	Description
Computerisation	Support through IT-Systems and worker will be disburdened from repetitive work
Connectivity	Systems are structured and connected
Visibility	Digital Shadow available and management decisions are data-based
Transparency	Companies understand why things happen
Predictive capacity	Companies know what might happened and decisions are based on future scenarios
Adaptability	Systems react and adapt autonomously

implemented in the SSCRM framework instead of the original stages of Norrman and Lindroth (2004): risk identification (identification of risks and sources); risk analysis (measurement of risk consequences and identification of risk factors); risk assessment (evaluation of risks); risk treatment (proposal of strategies and mitigation of risks) and risk monitoring (measurement of results, control of risks and ongoing improvement process).

The last dimension of the original framework describes the type of risk: operational, tactical and strategical (Norrman and Lindroth, 2004).

Because a SSCRM connects principles of I4.0 and SCRM the development goes along the same I4.0 maturity stages as mentioned in the literature. Recently the German acatech – National Academy of Science and Engineering published a study to provide companies with I4.0 maturity stages to help them identifying their current maturity stage and also to achieve a higher stage in order to maximize the economic benefits of I4.0 and digitalization (Schuh, et al., 2017). The maturity stages are described in the table below (see table 1).

When speaking about I4.0, the focus is usually on the technological aspects and the important role of CPS, but often neglected is the fact that CPS-based production systems are socio-technical systems (Hirsch-Kreinsen, 2014), consisting of a technical and social subsystem which are interlinked (Bostrom and Heinen, 1977). The social sub system focuses on the role of people using the technology while the technical sub system focuses on the available technology and its role (Bostrom and Heinen, 1977). Because future publications are not necessarily

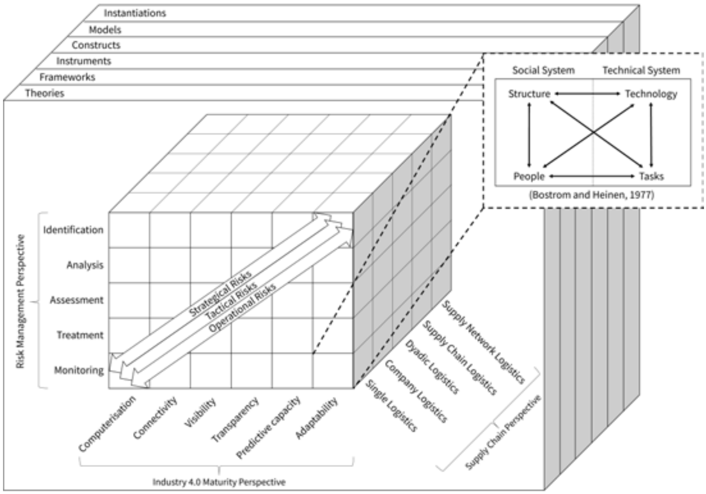

Figure 1: SSCRM Research Framework

focusing on the technological aspects of SSCRM but more on the social aspects and the dynamics between people and technology, the framework should also reflect this.

To speed up research in SSCRM an additional research-outcome dimension is required. The field of Design Science Research (DSR) has strongly formalized possible research outcome in the form of artifacts. DSR has the goal to develop practical solutions that can be used by professionals in their field (Lessard and Yu, 2012). A comprehensive list of how artifacts can look like comes from Hevner, et al. (2004), who mention theories, frameworks, instruments, constructs, models, methods and instantiations.

Combining the above mentioned dimensions delivers the following SSCRM framework, which answers the first research question (see figure 1).

The proposed framework now allows the classification of existing and current research regarding the field of SSCRM. A detailed explanation of the combined perspectives “Risk Management” and “Industry 4.0 Maturity” follows in the next chapter.

4 SSCRM Requirements Framework

To support practitioners in designing SSCRM systems requirements it is helpful to define how the aforementioned I4.0 maturity stages become manifest within SCRM. While the general descriptions of the I4.0 maturity stages (see section 3 and Schuh, et al., 2017) and SCRM (see section 3 and de Oliveira, et al., 2017) are given, the authors defined how the traditional SCRM phases could look like in SSCRM. The goal is to give practitioners a guiding instrument for deriving individual requirements for SSCRM systems throughout the SCRM process, for the technology as well as for the people using the technology.

Due to some similarities between SCRM steps and I4.0 maturity stages (e.g. Risk Analysis and Transparency) it is necessary to specify the objectives within the SCRM phases in an I4.0 context. Due to the digitalization of SC processes, future SC can be understood as data points in a Digital Shadow (Leveling, et al., 2014), leading to the following general SCRM objectives (just for orientation - degree of automatization depends on SSCRM maturity level) (see table 2):

Based on this specification and in combination with the I4.0 maturity stage definitions a framework could be derived, giving overview about potential SSCRM development stages (see table 3 – table 7). For the framework development previous work by Schlüter, Diedrich and Güller (2017) has been used to get an idea how the traditional SCRM phases will change through digitalization. These ideas have been further refined in brainstorming sessions and discussions with other researchers for this working paper. In the future additional research will take place to verify the authors’ ideas.

This first attempt of describing the roles of technology and people within a SSCRM answers the second research question. As it can be seen in the first and second maturity stage there are only marginal difference between the SCRM phases. The reason is that accordingly to (Schuh, et al., 2017) in these stages there is not yet an I4.0 environment and thus there is no infrastructure for a SSCRM available. The SC IT systems serve more as general data sources for risk managers who use the data supportive to traditional SCRM methods. After stage three the technology gets smart and more flexible and can be fitted to SCRM tasks.

Table 2: Overview SCRM objectives in I4.0 context

SCRM phase	Objective
Risk identification	Identification of new risk relevant data points and identification of relations between these points
Risk analysis	Identification of directions within the relations to create cause-and-effect relationships
Risk assessment	Realistic calculation of risks, based on the relationships between data points and objective quantitative data
Risk treatment	Identification of activities through data points and proposing of suitable activities based on effect analysis
Risk monitoring	Monitoring of known risks and risk relevant data points as well as chosen activities to ensure risk reduction

Table 3: SSCRM-Framework – Identification

I4.0 Readiness Stage	Technical System (Role)	Social System (Role)
Computerisation	Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally	Manager use the IT system records to identify potential risks in addition to workshops and expert interviews
Connectivity	Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base	Manager can use a broader range of SC process data to identify potential risks in addition to workshops and expert interviews
Visibility	All SC processes are represented and characterized through data points within a Digital Shadow via real-time data	The user has to recognize critical relations between the data points and define them as risks by himself
Transparency	Analytic systems recognize relations between data points (undirected relations) and they search for similar relations	Found relations have to be checked for criticality by the user
Predictive capacity	Simulation of scenarios within the Digital Shadow shows future relations between data points and how identified relations will change	Changes of relations and future relations have to be checked for criticality by the user
Adaptability	System recognizes potential critical relations between data points, aggregates them to risks and reports them to the user	User monitors the reports and uses the reported potential risky relations and aggregated risks as basis for further assessment and treatment

Table 4: SSCRM-Framework – Analysis

I4.0 Readiness Stage	Technical System (Role)	Social System (Role)
Computerisation	Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally	Manager use different IT system records, in addition to workshops and expert interviews to identify risk causes and patterns
Connectivity	Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base	Manager can use a broader range of SC process data, in addition to workshops and expert interviews to identify risk causes and patterns
Visibility	Every data point within each risk offers a range of qualitative, structured and semi-structured data	The user has to interpret the data of each data point to recognize cause-and-effect relations (directed relations)
Transparency	The system recognizes the cause-and-effect relations based on the real-time information from each data point within and without the identified risk cluster; Data points get ranked based on their influence on other points	The user has to check the data point ranking and chooses the points which should stay in focus for future risk treatment
Predictive capacity	Forecasting of changes of direction of the cause-and-effect relations	The user has to check the improved data point ranking and chooses the points which should stay in focus for future risk treatment
Adaptability	Based on previous capabilities the system gives suggestions on which data points should stay in focus for risk treatment	User checks the results for plausibility and uses the results for further assessment and treatment

Table 5: SSCRM-Framework – Assessment

I4.0 Readiness Stage	Technical System (Role)	Social System (Role)
Computerisation	Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally	In addition to expert estimations available process data can be used to calculate more reliable values for probability and impact
Connectivity	Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base	In addition to expert estimations the available broader range of process data can be used to calculate more reliable values for probability and impact
Visibility	Every data point within each risk offers a range of quantitative data and KPIs	Assessment of risks based on the KPIs and comparison with reference values
Transparency	Connecting of KPIs and thus improved calculation of impact; Calculation of probability based on a large number of historical and real-time data; Development of new risk measures where necessary	Manual comparison of actual risk values with reference values
Predictive capacity	Prediction-based risk calculation gives an overview about the actual and potential risk development	Manual comparison of actual and prediction-based risk values with reference values
Adaptability	Comparison of actual and potential risk development with reference values and automatic report in case of significant deviation	User checks the calculated values and reacts when the system gives a report/warning

Table 6: SSCRM-Framework – Treatment

I4.0 Readiness Stage	Technical System (Role)	Social System (Role)
Computerisation	Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally	Treatment actions are developed in workshops and improved cost-value ratio calculation based on process data.
Connectivity	Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base	Treatment actions are developed in workshops and improved cost-value ratio calculation based on broader range of available process data.
Visibility	Treatment activities are characterized through data points within the Digital Shadow	Based on the characterized risks the user has to identify suitable mitigation actions through the data points as well as to select and initiate them
Transparency	The system recognizes relations between risk data points and treatment activity data points and clusters them to potential actions as well as reports them to the user	Found actions and their effects have to be estimated, selected and initiated by the user
Predictive capacity	Potential actions will be simulated and the results serve as decision support. Additionally potential negative impacts on other risk data points can be recognized in advance	User chooses the actions with the best possible outcome or with the least side effects
Adaptability	After the evaluation the system decides autonomously about the initiation of mitigation actions	User checks the chosen actions and intervenes/-corrects if necessary

Table 7: SSCRM-Framework – Monitoring

I4.0 Readiness Stage	Technical System (Role)	Social System (Role)
Computerisation	Isolated usage of IT systems in SC processes allows the collection of structured and unstructured process data; Risk relevant information can be stored locally	At discrete points in time manager come together and discuss about monitored risks and initiated treatment actions, supported by available process data
Connectivity	Connection of IT systems allows the uni- or bidirectional exchange of process data; Risk relevant information can be stored in a process wide data base	At discrete points in time manager come together and discuss about monitored risks and initiated treatment actions, supported by a broader range of available process data
Visibility	Identified risks and where necessary initiated actions appear as individual entities in the Digital Shadow	User has to recognize plan deviations by himself and identify the reasons
Transparency	In case of a plan deviation the system tries to identify the reasons and reports them to the user	Based on the reports the user has to adapt the initiated actions or choose other options reactively
Predictive capacity	Due to a projection of the digital shadow into the future potential plan deviations and reasons can be recognized in advance; Corrective actions and their effectiveness can be simulated in advance	Based on the reports the user has to adapt the initiated actions or choose other options proactively
Adaptability	Autonomous correction of actions in case of a potential plan deviation	User supervises the system and corrects actions in case when plan deviations cannot be contained through the system

5 Conclusion and Further Research

The paper presents a first approach of establishing SSCRM as sub-research field of SCRM by proposing a specific research framework. The framework has been created by reviewing literature from the field of SCRM and I4.0. Afterwards a framework with SSCRM requirements has been developed as a guiding design instrument.

5.1 Limitations and further research

The proposed framework is only one way to define the sub-research field of SSCRM and was created by combining an established SCRM research framework with recent literature about I4.0. When more literature is available, further research can be suggested for testing if these dimensions are sufficient or additional dimensions have to be considered. Also the SSCRM phases and based on that the roles of technology and people within the SSCRM maturity stages have been postulated by the authors. Additional research will be undertaken to verify the authors' ideas, leading to generalized roles for individual requirement derivation. It also has to be noted that some framework dimension combinations may not allow some of the artifacts as a research outcome. This issue can be solved through screening future literature focusing on their position in the research field and their outcome.

5.2 Managerial Implications

The smart SCRM developed here is a good basis for a proactive SCRM which in the literature is discussed on a conceptual basis for many years (e.g. Henke, 2009) but up to now it has rarely been realised in business practice. In the age of Big Data, digitisation and autonomisation today we have sufficient data as well as the technologies (such as blockchain), which can allow a proactive management of such data along supply chains. The transparency in value-added networks exists end-to-end so that in the future risks can be avoided or reduced at an earlier stage than today. For a practical application of such a SSCRM it is also necessary that there is a structured approach from application-oriented research to core elements of a cycle of SSCRM.

References

Bauernhansl, T., M. ten Hompel, and B. Vogel-Heuser, eds. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung - Technologien - Migration*. Wiesbaden: Springer Fachmedien.

Bischoff, J., C. Taphorn, D. Wolter, N. Braun, M. Fellbaum, A. Goloverov, S. Ludwig, T. Hegmanns, C. Prasse, M. Henke, M. ten Hompel, F. Döbbeler, E. Fuss, C. Kirsch, B. Mättig, S. Braun, M. Guth, M. Kaspers, and D. Scheffler (2015). *Erschließen der Potenziale der Anwendung von 'Industrie 4.0' im Mittelstand: Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi)*. Ed. by J. Bischoff. Mülheim an der Ruhr.

Bostrom, R. P. and J. S. Heinen (1977). "MIS Problems and Failures: A Socio-Technical Perspective: PART I: THE CAUSES". In: *MIS Quarterly* 1.3, pp. 17–32.

Brindley, C., ed. (2004). *Supply chain risk*. Hanpshire, Burlington: Ashgate Publishing Ltd.

Bui, T. X. and R. H. Sprague, eds. (2016). *Proceedings of the 49th Annual Hawaii International Conference on System Sciences: 5-8 January 2016, Kauai, Hawaii*. Piscataway, NJ: IEEE.

Butner, K. (2010). "The smarter supply chain of the future". In: *Strategy & Leadership* 38.1, pp. 22–31.

Chopra, S. and M. S. Sodhi (2004). "Managing Risk To Avoid Supply-Chain Breakdown". In: *MIT Sloan Management Review* 46.1, pp. 53–61.

Curkovic, S., T. Scannel, and B. Wagner (2013). "ISO 31000:2009 - Enterprise and Supply Chain Risk Management: A Longitudinal Study". In: *American Journal of Industrial and Business Management* 3, pp. 614–630.

de Oliveira, U. R., F. A. S. Marins, H. M. Rocha, and V. A. P. Salomon (2017). "The ISO 31000 standard in supply chain risk management". In: *Journal of Cleaner Production* 151, pp. 616–633.

Fahimnia, B., C. S. Tang, H. Davarzani, and J. Sarkis (2015). "Quantiative Models for Managing Supply Chain Risks: A Review". In: *European Journal of Operational Research* 247.1, pp. 1–15.

Faisal, M. N., D. K. Banwet, and R. Shankar (2006). "Supply chain risk mitigation: modeling the enablers". In: *Business Process Management* 12.4, pp. 535–552.

Fan, H., T. C. E. Cheng, G. Li, and P. K. C. Lee (2016). "The Effectiveness of Supply Chain Risk Information Processing Capability: An Information Processing Perspective". In: *IEEE Transactions on Engineering Management* 63.4, pp. 414–425.

Fan, H., G. Li, H. Sun, and T. Cheng (2017). "An information processing perspective on supply chain risk management: Antecedents, mechanism, and consequences". In: *International Journal of Production Economics* 185, pp. 63–75.

Goh, R. S. M., Z. Wang, X. Yin, X. Fu, L. Ponnambalam, S. Lu, and X. Li (2013). "RiskVis: Supply chain visualization with risk management and real-time monitoring". In: *IEEE International Conference on Automation Science and Engineering (CASE), 2013*. Piscataway, NJ: IEEE, pp. 207–212.

Güller, M., E. Koc, T. Hegmanns, M. Henke, and B. Noche (2015). "A Simulation-based Decision Support Framework for the Real-time Supply Chain Risk Management". In: *International Journal of Advanced Logistics* 4.1, pp. 17–26.

Heckmann, I., T. Comes, and S. Nickel (2015). "A critical review on supply chain risk: Definition, measure and modeling". In: *Omega* 52, pp. 119–132.

Henke, M. (2009). *Supply Risk Management: Planung, Steuerung und Überwachung von Supply Chains*. Berlin: Erich Schmidt.

Hermann, M., T. Pentek, and B. Otto (2016). "Design Principles for Industrie 4.0 Scenarios". In: *Proceedings of the 49th Annual Hawaii International Conference on System Sciences*. Ed. by T. X. Bui and R. H. Sprague. Piscataway, NJ: IEEE, pp. 3928–3937.

Hevner, A. R., S. T. March, J. Park, and S. Ram (2004). "Design Science in Information Systems Research". In: *MIS Quarterly* 28.1, pp. 75–105.

Hillman, M. and H. Keltz (2007). *Managing Risk in the Supply Chain - A Quantitative Study*. Ed. by AMR Research.

Hirsch-Kreinsen, H. (2014). "Wandel von Produktionsarbeit - "Industrie 4.0"". In: *WSI Mitteilungen* 6, pp. 421–429.

Ho, W., T. Zheng, H. Yildiz, and S. Talluri (2015). "Supply chain risk management: a literature review". In: *International Journal of Production Research* 53.16, pp. 5031–5069.

Jüttner, U., H. Peck, and M. Christopher (2003). "Supply Chain Risk Management: Outlining an Agenda for Future Research". In: *International Journal of Logistics: Research and Applications* 6, pp. 197–210.

Kabashkin, I. V. and I. V. Yatskiv, eds. (2014). *Proceedings of the 14th International Conference "Reliability and Statistics in Transportation and Communication" (RelStat'14)*.

Kersten, W., T. Blecker, and C. M. Ringle, eds. (2015). *Sustainability in logistics and supply chain management: New designs and strategies*. 1st ed. Vol. 21. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin: epubli GmbH.

Kersten, W., M. Seiter, B. von See, N. Hackius, C. Rosentritt, C. Böhle, G. Reich, T. Maurer, and R. Sauter (2016). "Trends und Strategien in Supply Chain Management und Logistik - Chancen der digitalen Transformation". In: *Den Wandel gestalten*. Ed. by T. Wimmer and C. Grotemeier. Hamburg: Deutscher Verkehrs-Verlag, pp. 346–361.

Kilubi, I. and H. D. Haasis (2016). "Supply chain risk management research: Avenues for further studies". In: *International Journal of Supply Chain and Operations Resilience* 2.1, p. 51.

Lessard, L. and E. Yu (2012). "Using Design Science Research to Develop a Modeling Technique for Service Design". In: *DESRIST 2012, LNCS 7286*. Ed. by K. Peffers, M. Rothenberger, and B. Kuechler. Berlin, Heidelberg: Springer-Verlag, pp. 66–77.

Leveling, J., A. Schier, F. Luciano, and B. Otto (2014). "Konzeption eines proaktiven Risikomanagements in Logistiknetzwerken". In: *Logistics Journal : Proceedings* 2014.01.

Lindroth, R. and A. Norrman (2001). "Supply Chain Risks and Risk Sharing Instruments - An Illustration fromo the Telecommunication Industry". In: *Proceedings of the Logistics Research Network 6th Annual Conference*. Ed. by McKinnon, pp. 297–307.

Lu, Y. (2017). "Industry 4.0: A Survey on Technologies, Applications and Open Research Issues". In: *Journal of Industrial Information Integration*.

McKinnon, ed. (2001). *Proceedings of the Logistics Research Network 6th Annual Conference*.

Norrman, A. and U. Jansson (2004). "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident". In: *International Journal of Physical Distribution & Logistics Management* 34.5, pp. 434–456.

Norrman, A. and R. Lindroth (2004). "Categorization of Supply Chain Risk and Risk Management". In: *Supply chain risk*. Ed. by C. Brindley. Hanpshire, Burlington: Ashgate Publishing Ltd., pp. 14–27.

Peffers, K., M. Rothenberger, and B. Kuechler, eds. (2012). *DESRIST 2012, LNCS 7286*. Berlin, Heidelberg: Springer-Verlag.

Pettit, T. J., K. L. Crocton, and J. Fiksel (2013). "Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool". In: *Journal of Business Logistics* 34.1, pp. 46–76.

Pfohl, H.-C., B. Yahsi, and T. Kurnaz (2015). "The Impact of Industry 4.0 on the Supply Chain". In: *Sustainability in logistics and supply chain management*. Ed. by W. Kersten, T. Blecker, and C. M. Ringle. Vol. 21. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin: epubli GmbH, pp. 31–58.

Ponis, S. T. and A. C. Ntalla (2016). "Supply Chain Risk Management Frameworks and Models: A Review". In: *International Journal of Supply Chain Management* 5.4, pp. 1–11.

Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things: ICIT 2015 : January 17-18, 2015, Harbin, China (2015). Piscataway, NJ: IEEE.

Qin, J., Y. Liu, and R. Grosvenor (2016). "A Categorical Framework of Manufacturing for Industry 4.0 and Beyond". In: *Procedia CIRP* 52, pp. 173–178.

Ritchie, B. (2007). "Supply chain risk management and performance: A guiding framework for future development". In: *International Journal of Operations & Production Management* 27.3, pp. 303–322.

Roth, A., ed. (2016a). *Einführung und Umsetzung von Industrie 4.0: Grundlagen, Vorgehensmodell und Use Cases aus der Praxis*. Berlin, Heidelberg: Springer-Verlag.

Roth, A., ed. (2016b). *Einführung und Umsetzung von Industrie 4.0: Grundlagen, Vorgehensmodell und Use Cases aus der Praxis*. Berlin, Heidelberg: Springer-Verlag.

Roth, A. (2016c). "Industrie 4.0 - Hype oder Revolution?" In: *Einführung und Umsetzung von Industrie 4.0*. Ed. by A. Roth. Berlin, Heidelberg: Springer-Verlag, pp. 1–15.

Schlüter, F., K. Diedrich, and M. Güller (2017). "Analyzing the Impact of Digitalization on Supply Chain Risk Management". In: *2017 IPSERA Conference*.

Schröder, M., M. Indorf, and W. Kersten (2014). "Industry 4.0 and its Impact on Supply Chain Risk Management". In: *Proceedings of the 14th International Conference "Reliability and Statistics in Transportation and Communication" (RelStat'14)*. Ed. by I. V. Kabashkin and I. V. Yatskiv, pp. 114–125.

Schuh, G., R. Anderl, J. Gausemeier, M. ten Hompel, and W. Wahlster (2017). *Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies*. acatech STUDY. München: Herbert Utz Verlag.

Siepmann, D. (2016a). "Industrie 4.0 - Fünf zentrale Paradigmen". In: *Einführung und Umsetzung von Industrie 4.0*. Ed. by A. Roth. Berlin, Heidelberg: Springer-Verlag, pp. 35–46.

Siepmann, D. (2016b). "Industrie 4.0 - Technologische Komponenten". In: *Einführung und Umsetzung von Industrie 4.0*. Ed. by A. Roth. Berlin, Heidelberg: Springer-Verlag, pp. 47–72.

Singhal, P., G. Agarwal, and M. L. Mittal (2011). "Supply chain risk management: review, classification and future research directions". In: *International Journal of Business Science and Applied Management* 6.3, pp. 16–42.

Tang, C. and B. Tomlin (2008). "The power of flexibility for mitigating supply chain risks". In: *International Journal of Production Economics* 116.1, pp. 12–27.

Tang, O. and S. N. Musa (2011). "Identifying risk issues and research advancements in supply chain risk management". In: *International Journal of Production Economics* 133.1, pp. 25–34.

ten Hompel, M. and M. Henke (2017). "Logistik 4.0 – Ein Ausblick auf die Planung und das Management der zukünftigen Logistik vor dem Hintergrund der vierten industriellen Revolution". In: *Handbuch Industrie 4.0 Bd.4*. Ed. by B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel. Springer Reference Technik. Berlin, Heidelberg and s.l.: Springer Berlin Heidelberg, pp. 249–259.

Vogel-Heuser, B., T. Bauernhansl, and M. ten Hompel, eds. (2017). *Handbuch Industrie 4.0 Bd.4: Allgemeine Grundlagen*. 2nd ed. Springer Reference Technik. Berlin, Heidelberg and s.l.: Springer Berlin Heidelberg.

Wan, J., H. Cai, and K. Zhou (2015). “Industrie 4.0: Enabling technologies”. In: *Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things*. Piscataway, NJ: IEEE, pp. 135–140.

Wang, L. and R. Ranjan (2015). “Processing Distributed Internet of Things Data in Clouds”. In: *IEEE Cloud Computing* 2.1, pp. 76–80.

Wimmer, T. and C. Grotemeier, eds. (2016). *Den Wandel gestalten: Driving Change*. Hamburg: Deutscher Verkehrs-Verlag.

Zsidisin, G. A. and B. Ritchie (2009a). “Chapter 1: Supply Chain Risk Management - Developments, Issues and Challenges”. In: *Supply Chain Risk*. Ed. by G. A. Zsidisin and B. Ritchie. Vol. 124. International Series in Operations Research & Management Science. Boston MA: Springer-Verlag US, pp. 1–12.

Zsidisin, G. A. and B. Ritchie, eds. (2009b). *Supply Chain Risk: A Handbook of Assessment, Management, and Performance*. Vol. 124. International Series in Operations Research & Management Science. Boston MA: Springer-Verlag US.

Zweig, M., A. Agawal, B. Stall, C. Bremer, P. Mangers, A. Beifus, and M. Chauhan (2015). *Globalize or customise: finding the right balance: Global steel 2015-2016*. Ed. by EY.

Framework for Digitalized Proactive Supply Chain Risk Management

Katharina Diedrich[1]

1 – Technical University of Dortmund & Volkswagen Commercial Vehicles

In order to initiate proactive measures and to prevent the actual occurrence of risk events a digitalized and proactive supply chain risk management is needed.Existing approaches for digitalized and proactive SCRM are investigated by a systematic literature review and completed by a requirements engineering. Furthermore frameworks for SCRM are reviewed and the fulfillment of the requirements is checked. These results are applied to develop a digitalized and proactive SCRM framework.The findings in this paper are a profile of requirements and a framework, which enables a proactive management of forthcoming risks. Therefore an application of risk prediction and quantitative risk assessment in context of digitalized SCRM is used. The developed framework includes an adapted proactive SCRM process containing digitalized SCRM phases and digitalized SCRM methods, inter alia early knowledge and early assessment.

Keywords: Digitalized Proactive SCRM; Risk Information Integration; Risk Prediction; Risk Assessment

1 Introduction

Due to high outsourcing rates manufacturing companies are highly dependent on the performance of suppliers and supply chains (SC). Supply chain risks (SCR) can cause disruptions which lead to glitches. Glitches result in demand and supply mismatches and can have propagating effects on the entire SC. SCR is defined as the likelihood and impact of unexpected risk events which influence any part of the SC (Ho et al. 2015 p. 5035). A company's SC performance is depending on the degree of implementation of a supply chain risk management (SCRM) system (Thun & Hoenig 2011 pp. 246) and of assignment of responsibilities. Due to the crucial impacts and thereby high importance the management board should bear the responsibility for SCRM system planning, implementing and operating. The impact and probability of SCR occurrences for companies can be minimized with proactive SCRM systems and a high efficiency of company's SC processes can be enabled. The need for proactive SCRM has been identified by scientific researchers and managers in companies practice. Several recent published findings which cover the topic are available, while in the previous years before 2010 just a few papers were published. Due to the digitalization of SCs as well as the development of new technologies and SC partner collaborative approaches new potentials for proactive SCRM arise. In order to remain competitive and for economical production, companies have to deliberately take risks and accept a certain insecure risk situation. This publication investigates proactive SCRM approaches which accept the risk situation and focus on the management of individual forthcoming risk events.

1.1 SCRM Research Needs in the Field of Digital Transformation

Although the SCRM research field has gained a lot of attention during the last decade, the field of digitalized SCRM and proactive SCRM development is not considered adequately (Kırılmaz & Erol 2017, Kache & Seuring 2017 p. 20). Besides the scientific research gap, the need for proactive SCRM approaches in companies practice is urgent due to high number of risk events and the limitation to reactive firefighting systems (He et al. 2015 p. 1005, Kilubi & Haasis 2016 p. 66, Tang & Musa 2011 pp. 31). There have been some analyses conducted reviewing the SCRM literature in the recent past, which have a specific focus and thereby don't serve the objective of this publication. The past reviews have been focused on the purpose of SCRM studies (Vanany, Zailani & Pujawan 2009, Sodhi, Son & Tang

2012), definition of specific SCRM terms (Ho et al. 2015, Singh & Wahid 2014), risk classification (Qazi, Quigley & Dickson 2015, Tang & Musa 2011, Singhal, Agarwal & Mittal 2011), the SCRM process (Ho et al. 2015, Qazi, Quigley & Dickson 2015), risk sources (Kilubi & Haasis 2016), strategic changes in the field of SCRM (Ghadge, Dani & Kalawsky 2012), quantitative models for SCRM (Heckmann, Comes & Nickel 2015, Fahimnia et al. 2015) and relationship between SCRM and performance (Kilubi & Haasis 2016). The SCRM procedure has become a key issue of this research field. Most literature review publications show an analysis of SCRM publications in general, whereas the focus on proactive SCRM and the Digital Transformation of SCRM is missing. There is a research need for quantitative and model based proactive SCRM approaches (Kırılmaz & Erol 2017 pp. 62, Tang & Musa 2011 p. 32). These models should take interdependencies between dynamic risks and the risk propagation along the SC into account (Qazi, Quigley & Dickson 2015). In addition to material flow, for SCRM information flow and financial flow ought to be considered in depth (Tang & Musa 2011 p. 32). In addition to the analysis of Schlüter, Diedrich & Güller 2017 for digitalized approaches for the SCRM phases a comprehensive framework is needed which includes digitalized approaches and applies them for a proactive SCRM procedure.

1.2 Objective and Research Methodology

The objective of this paper is the development of a proactive SCRM framework which takes the Digital Transformation of the environment and of SCs that is currently taking place as well as the arising potentials for SCRM into account. In order to meet this objective, a Systematic Literature Review (SLR) is conducted. Due to the small number of publications regarding proactive SCRM, the keyword search of the SLR is extended to proactive SCRM and SCRM Frameworks. This paper explores the above described research gap regarding scientific approaches for proactive SCRM.

Hence, a SLR was conducted, targeting to collect and analyze relevant publications regarding proactive SCRM approaches. This SLR is used for the analyzation of proactive SCRM approaches and for the description of the research gap concerning proactive SCRM. For the following development of a proactive SCRM framework a requirements gathering has to be conducted. Requirements were derived from SLR findings and the results are applied to develop a digitalized and proactive SCRM framework. In addition specific features of risk assessment will be outlined and suggestions for further research conclude this paper.

2 Perspectives in Proactive SCRM

2.1 Digitalized SC Function as an Enabler for Advanced SCRM

New technologies enable the digitalization of SCs. These technologies are for example near field communication (NFC), radio frequency identification (RFID), barcode and machine sensors. New technologies are applied in research fields which are part of Digital Transformation and Industry 4.0, such as cyber-physical systems, cloud computing, smart factory and internet of things (Kersten, Schröder & Indorf 2015). From these applied technologies in supply chain management and logistics new data sources arise which enable a data driven management of SCRs by application in appropriate methods. For efficient SCRM an advanced SC information management is required, which contains a supplier data base including master data of n-tier supplier, production sites, and further specific knowledge. The knowledge management and visualization of SC and the SCR information processing in the context of Digital Transformation and the associated data generation is still an unexplored research field (Fan et al. 2017, Biswas & Sen 2016). Current key challenges of the Digital Transformation of SC and SCRM are data islands, silo mentality and insufficient cooperation let alone collaboration of data availability. The Supply Chain Shadow as a virtual representation of a SC is enabled by the digitalization of SCs and the accompanying availability of real-time data (Henke 2017). The concept of the Supply Chain Shadow uses the available data in a virtual information and knowledge transfer.

2.2 Digitalized Proactive SCRM Approaches

The digitalization of SCRM is based on digitized SCs and enhanced technologies and methods. Available real-time data regarding SCRs result from applied technologies. New potentials for digitalized SCRM have been analyzed by Schlüter, Diedrich & Güller 2017, their findings are summarized in an overview of existing approaches which take digitalized methods for the phases identification, assessment, treatment and monitoring & control and thereby a digitalization of the SCRM procedure into account. A resulting change in the SCRM procedure is the parallelized pass through of risks in the digitalized procedure (Schlüter, Diedrich & Güller 2017 p. 6). Thereby the phases don't have to be processed sequentially by long-term committees anymore and risks can be handled simultaneous in different phases.

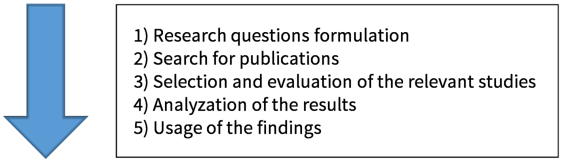

Figure 1: SLR method

3 Systematic Literature Review for Proactive SCRM

The SLR conducted in this paper is based on the methodical approach described by Seuring & Gold 2012, as can be seen in figure 1. A SLR is a transparent, reproducible scientific method which targets to cover the state of research with a specific research focus defined by the following research questions (RQ):

RQ1: Do the proactive SCRM frameworks, methods or approaches correspond with the introduced definition for proactive SCRM?

RQ2: Do the approaches take new potentials for proactive SCRM arising from the Digital Transformation into account?

RQ3: Which requirements for a proactive SCRM Framework can be raised?

Found publications are selected as relevant by use of assessment criteria (AC):

AC1: Future-oriented methods for the phases of the SCRM process

AC2: Management of forthcoming risks while accepting the risk situation

AC3: Potentials for SCRM which result from the Digital Transformation of SCs & SCRM itself

AC4: Further aspects of proactive SCRM

The first AC shall bring attention to forthcoming risks. The AC2 has to be described further for a deeper insight: The bearable risk situation of a company depends on the SC dependency, buffers, flexibility and further aspects, whereat no guidelines exist that describe how much risk a company should accept. The higher the accepted risks are, the more chances can be taken and the higher is the impact of potential risks. The company's risk situation is accepted to gain chances by accepting risks and this paper targets at not changing the risk situation and existing

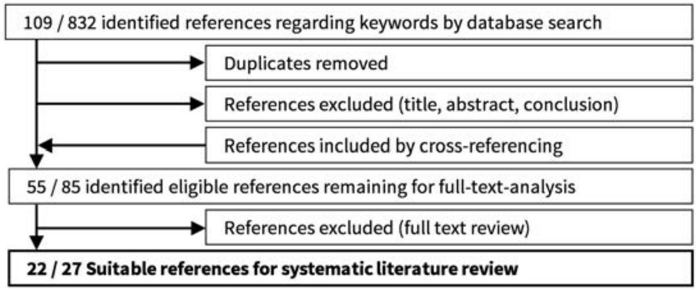

Figure 2: Number of references

structures. Therefore the optimization of the risk situation by preventive management and not taking the risks is explicitly not looked for. The third AC refers to the application of new technologies and methods for deeper risk knowledge and management improvement. AC4 targets the open search for further aspects or approaches which serve the proactive SCRM. SCRM framework publications are assessed based on in-depth description of reactive SCRM frameworks. After selection of papers the full paper review process and the content analysis have been carried out. These findings are introduced in the following section.

3.1 Analytical Description of Publications

For answering these research questions appropriate publications are reviewed with the year of publication between 2000 and June 2017. The applied keywords for database search are proactive supply chain risk management and framework supply chain risk management. The database SCOPUS.COM was most suitable for this search, as Fahimnia et al. 2015 has described before. SCOPUS includes e.g. Wiley, Taylor & Francis, Emerald, IEEE Xplore and Springer. Thereby the search is open to several journals and conferences and limited by the application of the defined keywords.

The resulting numbers of publications are shown in figure 2, whereby the first number refers to proactive SCRM and the second number to SCRM framework publications. The analysis of the distribution of suitable publications over the year

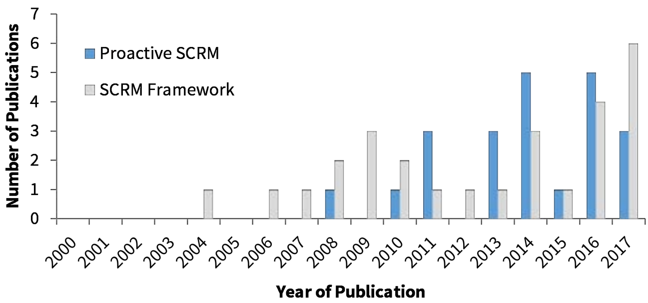

Figure 3: Years of publication of suitable publications

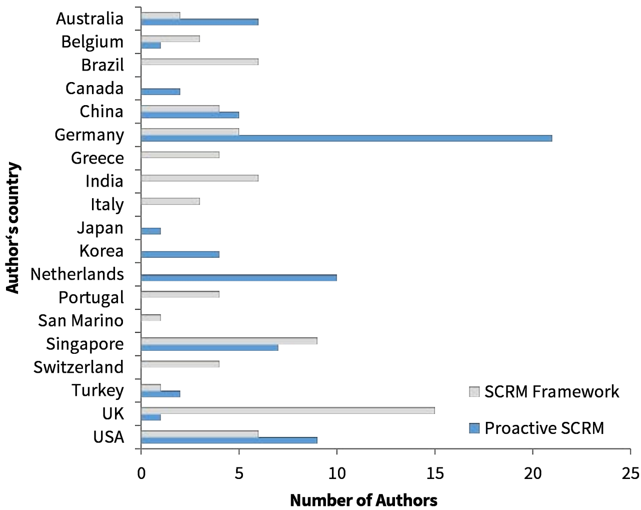

Figure 4: Authors countries of suitable publications

of publication is shown in figure 3. This analysis shows a significant research interest in proactive SCRM since 2008. There are just a small number of approaches for proactive SCRM in scientific literature available, which confirms the research gap for proactive management.

The suitable publications are published in Journals (15/18) and conferences (7/9). This shows that conferences are an important research platform for SCRM and shouldn't be neglected in SLR. The countries of publishing authors are visualized in figure 4.

3.2 Content Analysis of Proactive SCRM Publications

The suitable SCRM framework publications show SCRM procedure approaches, but none of these are proactive approaches. In literature the terms reactive, preventive and proactive SCRM are often used, but the definition and understanding of the term proactive SCRM differs in the literature even though many publications refer to proactive SCRM (Qazi, Quigley & Dickson 2015). Many publications use the term "proactive" but actually don't meet the ACs for proactive SCRM and are rather preventive approaches. The term proactive SCRM is often applied to approaches which should be assigned to preventive SCRM, because these approaches change SC structures, apply alternative strategical approaches, for example dual sourcing, and by not taking on risks any longer improve the risk situation. None of the reviewed publications give a definition for proactive SCRM. The author's understanding and definition of proactive SCRM is as follows: Proactive SCRM approaches target to gain action time for management of individual forthcoming SCR and thereby can be described as ex ante management while accepting the risk situation of a company in a SC network. A common, but not defined, understanding can be found in applicable publications, such as Rotaru, Wilkin & Churilov 2014 and Leveling et al. 2014. The remaining suitable publications meet at least one AC (8), whereas no publication meets all ACs, as can be seen in figure 5.

To gain the ability of proactive SCRM a high level of technical abilities has to be achieved. Furthermore the research field of digitalized and proactive SCRM is fast growing, so that the existing reviews are no longer up to date, which was confirmed by the conducted review.

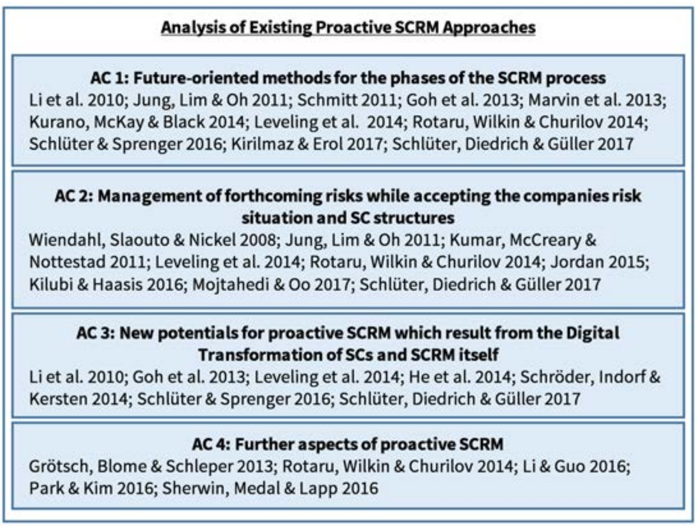

Figure 5: Analysis of proactive SCRM approaches

3.2.1 Proactive SCRM Approaches (RQ1)

Real-time risk monitoring and SC visualization is proposed by Goh et al. 2013 for early alert to achieve proactive SCRM. This might enable in-time knowledge regarding SC structures and dependencies but no future oriented knowledge which is required for proactive management. Leveling et al. 2014 describe data integration and Schlegel 2015 underlines the importance of immediate risk information and knowledge which can be gained by big data and predictive analytics, nonetheless a concrete description of application of analytics for proactive SCRM and inclusion in SCRM phases is not considered by found approaches.

Most publications which refer to a SCRM process describe the phases identification, assessment, mitigation and control (Ho et al. 2015). Other publications variate these phases to special requirements for proactive SCRM which contain for example a prioritization based on risk evaluation, risk criteria and the differentiation between tolerable and not acceptable risk events (Kırılmaz & Erol 2017 p. 57). Kırılmaz & Erol 2017 describes the phases of identification, measurement, evaluation, mitigation and control.

The proactive approach of Kırılmaz & Erol 2017 is based on shifting orders among suppliers and contains a quantitative model for proactive SCRM, which takes costs and risk aspects for procurement into account. Approaches for selection and combination of action measures can be found in for example Ghadge, Dani & Kalawsky 2012 p. 324.

3.2.2 Proactive SCRM Potentials Arise from Digital Transformation (RQ2)

For answering this research question lots of cross referencing and further information gathering had to be carried out. Only seven of the located publications found by the SLR referred to new technologies, Digital Transformation of SCs and risk management, data mining or predictive analytics, which shows the research need for Digital Transformation of scientific approaches for proactive SCRM. A research gap aspect is the consideration of available information, the uncertainties involved and the information integration into the SCRM procedure (Rotaru, Wilkin & Churilov 2014 p. 12, Fan et al. 2017). This future research need includes readily available, timely and accurate risk information and can be gained by application of information and communication technologies such as RFID, GPRS and social networks (Ghadge, Dani & Kalawsky 2012 p. 328, Chae 2015). The application of

Proactive SCRM Approaches

- Proactive planning
- Supplier selection
- Structural optimization of SC and dependencies
- Shifting orders among suppliers

Objectives of Proactive SCRM

- Precaution against risky suppliers
- Cost-efficiency of risk management procedures
- Minimization of damage in case a disruption occurs
- Prevention of supply delays or interruptions
- Cost-effective and time-saving mitigation

Components of Proactive SCRM

- Data integration
- Real-time monitoring
- Risk prediction
- Assessment of forthcoming risks
- Selection and combination of action measures for forthcoming risk events
- Visualization

Figure 6: SLR findings regarding proactive SCRM

big data analytics can provide SC visibility and thereby support decision making for SCRM (Seele 2017, Wang et al. 2016, Ghosh 2015, Schoenherr & Speier-Pero 2015, Leveling, Edelbrock & Otto 2014). This small number of publications refers to the application and advantages of data-driven analytical approaches in SCRM, but they rarely refer to risk management processes. The application of data mining and predictive analytics for SCRM is still a research gap. Future implications for SCRM based on digitalized approaches and digitalized approaches for conventional SCRM phases have been analyzed and summarized by Schlüter, Diedrich & Güller 2017.

3.2.3 Requirements for a Proactive SCRM Framework (RQ3)

SCRM phases are rather complex process phases which interact with each other and require a high level of technical abilities. A high number of publications describing SCRM process phases exist in scientific literature. Within this research question SCRM frameworks with characteristics for proactive management are analyzed.

Ponis & Ntalla considered 16 SCRM framework models as adequate, of which none is published after 2013 (Ponis & Ntalla 2016 p5). During the SLR of this publication there have been found 43 SCRM framework publications with a publication date of 2013 or newer, which have to be examined for requirement fulfillment to complement the SLR conducted by Ponis & Ntalla.

The framework designed by Aqlan & Lam 2015 includes risk prediction, but further description of risk prediction methods and time dependency of risk analysis are missing (Aqlan & Lam 2015).

He et al. 2015 show the potential of risk prediction, risk simulation & evaluation and risk mitigation as key process components to support the SCRM process, but a transfer to a comprehensive proactive SCRM framework and proactive SCRM procedure is still missing. The key process components are executed sequentially (He et al. 2015 p. 1008).

SCRM as part of SCM calls for technical competence and for new technological solutions to enable new SCRM approaches based on big data (Leveling et al. 2014 p. 6).

Mangla, Kumar & Kumar Barua 2014 have identified important factors for SCRM and SC sustainability. Some of these factors can be understood as requirements

Profile of Requirements for Proactive SCRM

- Adaption of SCRM phases, to enable a future-oriented and active SCRM procedure
- Automatization and parallelization of SCRM phases instead of sequentially pass-through of SCRM phases in committees
- Orientation of proactive SCRM phases on individual forthcoming risk events (instead of for example assessment of risk categories like any natural disasters)
- Access to internal and external supply chain information
- Knowledge and transparency of SC structures and dependencies
- Knowledge and understanding about supply chain risks
- Up-to-date knowledge and in-depth information on forthcoming risks
- Quality and reliability of supply chain risk information
- Strategic risk planning
- Early identification and detection of forthcoming risks
- Assessment of forthcoming risks
- Early measure generation
- Selection and combination of optimal actions
- Uninterrupted information chain along the supply chain for risk management, which calls for collaboration among supply chain partners
- Collaborative SCRM approaches: Common proactive SCRM strategies, decision and information sharing among SC partners

Figure 7: Requirements for proactive SCRM

for proactive SCRM, inter alia knowledge and understanding about SCRs, strategic risk planning, SC integration, security issues knowledge, network and global complexion understanding, SC visibility and mutual transparency as well as decision and information sharing (Mangla, Kumar & Kumar Barua 2014 pp. 127). A research project supported by the BMWi, Germany showed the timely identification of SCR as a key issue for proactive SCRM (Cirullies & Kamphues 2014).

The profile of requirements for a proactive SCMR framework is summarized in figure 7. The requirements for proactive SCRM have been derived from existing proactive approaches and supplemented by requirements which have beforehand been raised in a workshop with SCRM research experts.

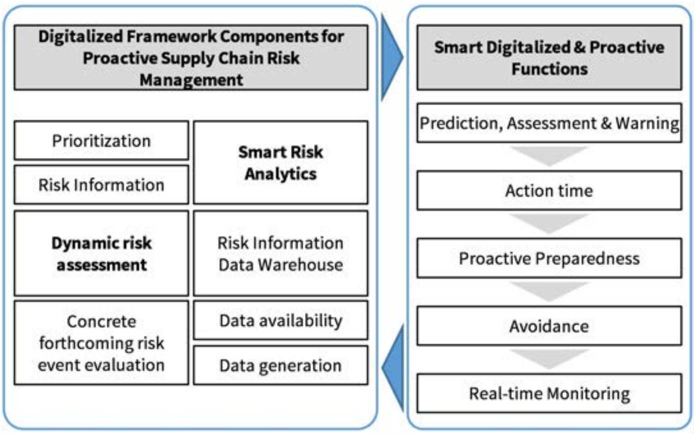

Figure 8: Digitalized SCRM components

4 Conceptual Framework

The terms approach, model, method, concept, procedure and framework are often synonymously applied for the description of a complex management approach (Vogel & Lasch 2015 pp. 102). The objective of this section is the development of a proactive management approach. Due to digitalization of SC and SCRM, the use of data, tools and analytical approaches is steadily increasing. Components for a digitalized and proactive SCRM framework are shown in figure 8.

The requirements for proactive SCRM can be fulfilled by the development of new methods for an advanced early-warning-system, which contains innovative aspects of the proactive SCRM framework, including smart risk analytics and risk prediction methods. As figure 9 shows, in addition to the early warning system an adaption of SCRM phases for management of future risks in a proactive procedure is developed.

The risk identification phase and risk assessment phase should be connected in a single comprehensive phase, because the identification of a risk requires knowledge regarding the risk assessment and especially risk impact for managers

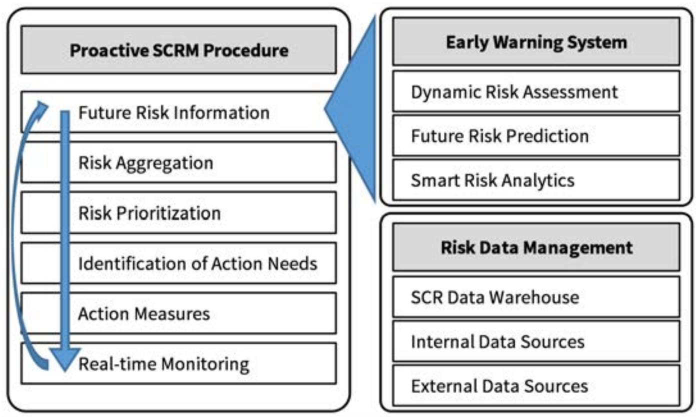

Figure 9: Digitalized proactive SCRM framework

to be able to recognize an event as a risk with a negative impact to a company or a SC network. Therefore these phases are connected in the early warning system, as can be seen in figure 9.

Risk prediction and quantitative risk assessment for future SCRs are core competences of the framework. In the following the use of data mining, big data and predictive analytics for proactive SCRM is referred to as smart risk analytics.

The collection of company and SC data from a wide range of internal and external data sources, inter alia social networks, natural disaster prediction, transportation data, stock data, material flow data and internal process and planning data, is a prerequisite for smart risk analytics. Natural disaster risks information, for example earthquakes, can be combined with industrial data and geographical data for risk sensing, assessment and predicting future events (Seele 2017 p. 684, Rajesh 2016, He et al. 2015 p. 1009, Schlegel & Trent 2015, Schlegel 2015). Smart risk analytics enables an intelligent and proactive SCRM based on the digitalization of SCs and risk management processes targets at concrete risk information for forthcoming SCR. Smart risk analytics can help assessing and managing SCR and distinguishing between risks that should be avoided and risks that should be taken (Wang et al. 2016 p. 101, p. 103). Information processing for

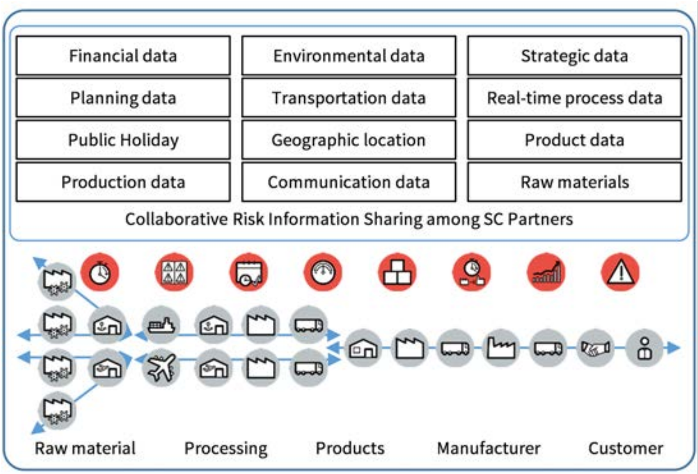

Figure 10: Risk information layer and data sources

SCRM, risk analysis and assessment as well as sharing of risk information should be processed proactively (Fan et al. 2017 p. 67).

For achieving smart risk analytics, the key function of the framework risk data management is needed, which leads to a high level of risk information and knowledge. Collected data has to be stored, made available and maintained in real-time to achieve potentials of SC digitalization. This enables a rapid analysis of information streams to generate real-time risk information and by application of predictive analytics risk forecasting abilities.

According to the information layer of the described Supply Chain Shadow, developed by Henke 2017, a risk information layer is described in figure 10. A variety of internal and external data sources have to be integrated in risk data management.

There is also need for research regarding the evaluation and further development of risk assessment, inter alia based on multi-criteria evaluation methods (Rotaru, Wilkin & Churilov 2014 p. 12). The extended functions of an adapted procedure

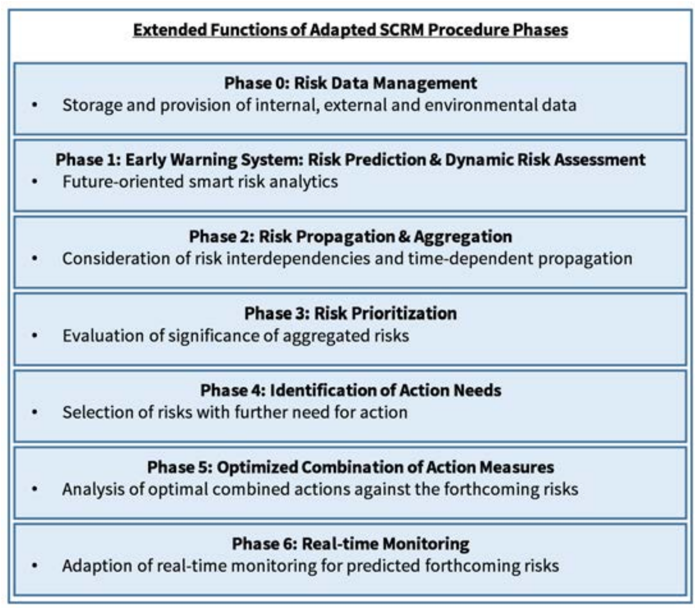

Figure 11: Adapted SCRM Phases

are core competencies of the framework, as can be seen in figure 9, and are further described in figure 11. The functions are based on SLR findings and completed with companies requirements in practice and own developed approaches. Especially the risk assessment phase has to be processed beforehand and thereby ex ante to risk events. This phase enables the triggering of the following proactive procedure.

Rapid risk assessment can be achieved by development of appropriate tool solutions (Aqlan 2016 pp. 110). Approaches of quantitative risk assessment can be found in Fahimnia 2015 and Dong & Cooper 2016. The forward-looking method is a key function for proactive SCRM procedure, hereafter referred to as dynamic risk assessment. The method of an ex ante risk assessment is based on knowledge and information of forthcoming SCR.

Risk events are linked to SC processes and performance, which themselves can trigger further risk events and decrease the SC performance. Besides this, simultaneous occurring events can increase or diminish the probability and impact. The dynamic time-dependent risk behavior, risk interdependencies and the propagation of SCR along the entire SC has to be considered for risk assessment and proactive approaches. This research field is relatively unexplored, but first approaches can be found in for example Ghadge, Dani & Kalawsky 2012 p. 329 and Qazi, Quigley & Dickson 2015 p. 7.

Further research is required to include risks which do not occur frequently and for which no historical data is available. The methodical approach of risk aggregation should also take risk propagation along the SC into account. Depending on the risk propagation along the SC an individual risk measure for the SC partner as a viewing point has to be aggregated.

The combination of smart risk analytics and dynamic risk assessment enables a smart forward looking risk action and is the functionality of the described early warning system component of the proactive SCRM framework. It can be inferred from this, that the potential of proactive management and the ability to generate action time before a risk event occurs is enabled by the combination of existing SCRM methods, the adaption of SCRM phases and the development of time-depending and forward-looking innovative methods.

The prioritization of risks is needed by risk managers to detect the most urgent need for action and to focus on these risks (Aqlan & Lam 2015 p. 55), and thereby should be part of a proactive SCRM system. Those risks should be high prioritized, which are most likely to stop or disturb the production, and those risks which might lead to high financial losses for the manufacturing company. However, in order to evaluate the whole dimension of forthcoming risks, the risk prioritization requires the consideration of risk interdependencies and risk aggregation as described above.

For proactive SCRM approaches, the prioritization has to be linked to information which gives deeper insights into the risk sources, remaining action time and potential measures to handle the risk events. Companies need reliable information to choose which risk should be handled with cost-intensive proactive measures. A visualization approach shows identified risks with need for proactive action in a risk heatmap (Singh & Wahid 2014 p. 64), which needs to be further developed to include dynamic time dependent information.

5 Conclusion and Discussion

The methodical approach of this paper ensures a reproducible compilation of scientific research and publications of the research fields of proactive SCRM and SCRM frameworks. For further improvement empirical validation in companies practice is still pending. The main limitations of the SLR result from used databases and keywords. This SLR includes only publications with respect to proactive SCRM approaches. Access to scientific publications is often limited. For this paper the access to SCOPUS.COM via university license was used and enabled access to many publications. Nonetheless a few publications were not available in digital form or not accessible. Open Access is a rather new and slowly spreading way to ensure access to scientific publications.

The major findings of this paper are an overview of existing approaches in the field of proactive SCRM and digitalization, comprehensive requirements for proactive SCRM as well as the development of a digitalized proactive SCRM framework. Individual risk prediction, defined as smart risk analytics, and time depending risk assessment, defined as dynamic ex ante risk assessment, are key components of this proactive SCRM framework. These components are enabled by the Digital Transformation of SCs.

Risk mitigation through collaboration has a high need for implementation (Ghadge, Dani & Kalawsky 2012 p. 328). The need for collaborative approaches of SC partners regarding collaborative decision making and strategies is high due to multiple dependencies and the risk propagation along the entire SC, which has to be initiated by management. Besides this, companies are reluctant to implement proactive SCRM processes because as Repenning & Sterman 2001 stated "nobody ever gets credit for fixing problems that never happened" (Tang 2006 p. 480). Moreover the key function of SCR prioritization has to be implemented - otherwise critical risks would simply be drowned by the flood of predicted risk events and made targeted action impossible. Figure 12 shows managerial implications of this paper.

From the findings of this paper a future research need for risk prediction and forward looking risk assessment with concrete time reference can be derived.

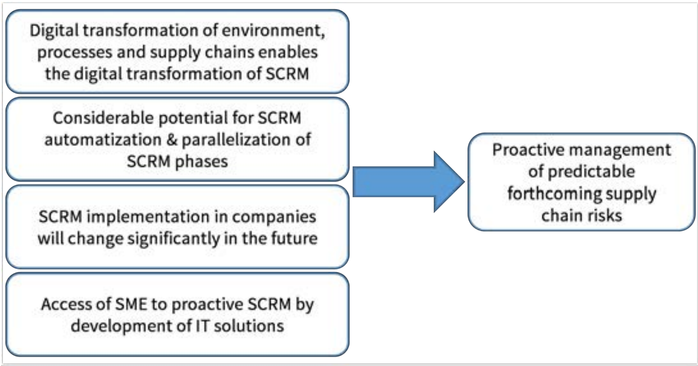

Figure 12: Significance of Digital Transformation and future research directions of SCRM

Both research gaps are correlated to higher information integration into the SCRM process. The high level information integration enables an objective and specific assessment of potential forthcoming risks. Furthermore research needs result from the limitations of the conducted SLR, so that smart risk analytics and early warning are further fields of research which have not been exploited with this analysis. Future research should be focused on risk assessment of forthcoming risks, smart risk analytics and early warning.

References

Aqlan, F. (2016). “A software application for rapid risk assessment in integrated supply chains”. In: *Expert Systems with Applications* 43, pp. 109–116.

Aqlan, F. and S. S. Lam (2015). “A fuzzy-based integrated framework for supply chain risk assessment”. In: *International Journal of Production Economics* 2015.161, pp. 54–63.

Biswas, S. and J. Sen (2016). “A Proposed Architecture for Big Data Driven Supply Chain Analytics”. In: *International Journal of Supply Chain Management*, pp. 1–24.

Chae, B. (2015). “Insights from hashtag #supplychain and Twitter Analytics”. In: *International Journal of Production Economics* 165, pp. 247–259.

Cirullies, J. and J. Kamphues (2014). *Integrierte Terminierung und Transportplanung unterstützt durch kollaboratives Risikomanagement in der Automobilindustrie: Schlussbericht*. Fraunhofer IML, Bundesministerium für Wirtschaft und Energie.

Dong, O. and O. Cooper (2016). "An orders-of-magnitude AHP supply chain risk assessment framework". In: *International Journal of Production Economics* 2016.182, pp. 144–156.

Fahimnia, B., C. S. Tang, H. Davarzani, and J. Sarkis (2015). "Quantitative models for managing supply chain risks". In: *European Journal of Operational Research* 2015.247, pp. 1–15.

Fan, H., G. Li, H. Sun, and T. Cheng (2017). "An information processing perspective on supply chain risk management: Antecedents, mechanism, and consequences". In: *International Journal of Production Economics* 185, pp. 63–75.

Ghadge, A., S. Dani, and R. Kalawsky (2012). "Supply chain risk management: present and future scope". In: *The international journal of logistics management* 23.3, pp. 313–339.

Ghosh, D. (2015). "Big Data in Logistics and Supply Chain Management". In: *2015 International Symposium on Advanced Computing and Communication (ISACC)*.

Goh, R. S. M., Z. Wang, X. Yin, X. Fu, and L. Ponnambalam (2013). "RiskVis: Supply Chain Visualization with Risk Management and Real-time Monitoring". In: *IEEE International Conference on Automation Science and Engineering (CASE)*, pp. 207–212.

Grötsch, V., C. Blome, and M. Schleper (2013). "Antecedents of proactive supply chain risk management". In: *International Journal of Production Research* 51.10, pp. 2842–2867.

He, M., H. Ji, Q. Wang, C. Ren, and R. Lougee (2015). "Big data fueled process management of supply risks". In: *Proceedings of the 2014 Winter Simulation Conference*, pp. 1005–1013.

Heckmann, I., T. Comes, and S. Nickel (2015). "A critical review on supply chain risk - Definition, measure and modeling". In: *Omega* 2015.52, pp. 119–132.

Henke, M. (2017). *Digitalisierung als Chance - Kollaboratives Management und Wissenschaftskooperationen für Smart Logistics*. Hannover: Presentation.

Ho, W., Z. Zheng, H. Yildiz, and S. Talluri (2015). "Supply chain risk management: a literature review". In: *International Journal of Production Research* 53.16, pp. 5031–5069.

Jung, K., Y. Lim, and J. Oh (2011). "A model for measuring supplier risk". In: *British Journal of Management* 2011.22.

Kache, F. and S. Seuring (2017). "Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management". In: *International Journal of Operations & Production Management* 37.1, pp. 10–36.

Kersten, W., M. Schröder, and M. Indorf (2015). "Supply Chain Risikomanagement für die Industrie 4.0". In: *Industrie 4.0 Management: Gegenwart und Zukunft industrieller Geschäftsprozesse* 31.3, pp. 36–40.

Kilubi, I. and H.-D. Haasis (2016). "Supply chain risk management research: avenues for further studies". In: *International Journal of Supply Chain and Operations Resilience* 2.1, pp. 51–71.

Kırılmaz, O. and S. Erol (2017). "A proactive approach to supply chain risk management: Shifting orders among suppliers to mitigate the supply side risks". In: *Journal of Purchasing and Supply Management* 23.1, pp. 54–65.

Leveling, J., M. Edelbrock, and B. Otto (2014). "Big Data Analytics for Supply Chain Management". In: *IEEE International Conference on Industrial Engineering and Engineering Management*, pp. 918–922.

Leveling, J., A. Schier, F. Luciano, and B. Otto (2014). "Konzeption eines proaktiven Risikomanagements in Logistiknetzwerken". In: *Logistics Journal: Proceedings*.

Li, Y., M. R. Kramer, A. Beulens, and J. van der Horst (2010). "A framework for early warning and proactive control systems in food supply chain networks". In: *Computers in Industry* 2010.61, pp. 852–862.

Li, Y. and Y. Guo (2016). "Be proactive for better decisions". In: *International Journal of Disaster Risk Reduction* 2016.19, pp. 75–83.

Mangla, S. K., P. Kumar, and M. Kumar Barua (2014). "Flexible Decision Approach for Analysing Performance of Sustainable Supply Chains Under Risk". In: *Global Journal of Flexible Systems Management* 15.2, pp. 113–130.

Mojtahedi, M. and B. L. Oo (2017). "Critical attributes for proactive engagement of stakeholders in disaster risk management". In: *International Journal of Disaster Risk Reduction* 2017.21, pp. 35–43.

Park, Y.-B. and H.-S. Kim (2016). "Simulation-based evolutionary algorithm approach for deriving the operational planning of global supply chains from the systematic risk management". In: *Computers in Industry* 2016.83, pp. 68–77.

Ponis, S. T. and A. C. Ntalla (2016). "Supply Chain Risk Management Frameworks and Models: A Review". In: *International Journal of Supply Chain Management* 5.4.

Qazi, A., J. Quigley, and A. Dickson (2015). "Supply Chain Risk Management: Systematic literature review and a conceptual framework for capturing interdependencies between risks". In: *Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management. Dubai, United Arab Emirates.*

Rajesh, R. (2016). "Forecasting supply chain resilience performance using grey prediction". In: *Electronic Commerce Research and Applications* 20, pp. 42–58.

Repenning, N. P. and J. D. Sterman (2001). "Nobody ever gets credit for fixing problems that never happened". In: *California Management Review* 43.4, pp. 64–88.

Rotaru, K., C. Wilkin, and L. Churilov (2014). "Proactive Risk Identification in Cross-organizational Business Processes". In: *25th Australasian Conference on Information Systems, Auckland, New Zealand* 2014, pp. 1–14.

Schlegel, G. L. (2015). "Utilizing Big Data and Predictive Analytics to Manage Supply Chain Risk". In: *Journal of Business Forecasting* 2014-2015.Winter, pp. 11–17.

Schlegel, G. L. and R. J. Trent (2015). *Supply chain risk management: An emerging discipline*. Boca Raton, Florida: CRC Press.

Schlüter, F., K. Diedrich, and M. Güller (2017). "Analyzing the Impact of Digitalization on Supply Chain Risk Management". In: *IPSERA Conference: International Purchasing and Supply Education and Research Association, Budapest / Balatonfüred, Hungary*.

Schlüter, F. and P. Sprenger (2016). "Mitigation framework for decentralised and proactive risk identification in a steel supply chain via industry 4.0 technologies". In: *5th International Symposium and 27th National Conference on Operation Research*, pp. 85–91.

Schoenherr, T. and C. Speier-Pero (2015). "Data Science, Predictive Analytics, and Big Data in Supply Chain Management: Current State and Future Potential". In: *Journal of Business Logistics* 36.1.

Schröder, M., M. Indorf, and W. Kersten (n.d.). "Industry 4.0 and its impact on supply chain risk management". In: *Reliability and statistics in transportation and communication* 2014.

Seele, P. (2017). "Predictive Sustainability Control: A review assessing the potential to transfer big data driven 'predictive policing' to corporate sustainability management". In: *Journal of Cleaner Production* 2017.153, pp. 673–686.

Seuring, S. and S. Gold (2012). “Conducting content-analysis based literature reviews in supply chain management”. In: *Supply Chain Management: An International Journal* 17.5, pp. 544–555.

Sherwin, M., H. Medal, and S. Lapp (2016). “Proactive cost-effective identification and mitigation of supply delay risks in a low volume high value supply chain using fault-tree analysis”. In: *International Journal of Production Economics* 2016.175, pp. 153–163.

Singh, G. and N. A. Wahid (2014). “Supply Chain Risk Management: A Review”. In: *International Journal of Supply Chain Management* 3.3, pp. 59–67.

Singhal, P., G. Agarwal, and M. L. Mittal (2011). “SCRM: review, classification and future research directions”. In: *International Journal of Business Science and Applied Management* 6.3, pp. 15–42.

Sodhi, M. S., B.-G. Son, and C. S. Tang (2012). “Researchers’ Perspectives on SCRM”. In: *Production and Operations Management* 21.1, pp. 1–13.

Tang, C. S. (2006). “Perspectives in supply chain risk management”. In: *International Journal of Production Economics* 2006.103, pp. 451–488.

Tang, O. and S. N. Musa (2011). “Identifying risk issues and research advancements in supply chain risk management”. In: *International Journal of Production Economics* 2011.133, pp. 25–34.

Thun, J.-H. and D. Hoenig (2011). “An empirical analysis of supply chain risk management in the German automotive industry”. In: *International Journal of Production Economics* 2011.131, pp. 242–249.

Vanany, I., S. Zailani, and N. Pujawan (2009). “Supply Chain Risk Management: Literature Review and Future Research”. In: *International Journal of Information Systems and Supply Chain Management* 2.1, pp. 16–33.

Vogel, W. and R. Lasch (2015). “Approach for Complexity Management in Variant-rich Product Development”. In: *Proceedings of the Hamburg International Conference of Logistics (HICL) - Operational Excellence in Logistics and Supply Chains* 2015, pp. 97–140.

Wang, G., A. Gunasekaran, E. W. T. Ngai, and T. Papadopoulos (2016). “Big data analytics in logistics and supply chain management: Certain investigations for research and applications”. In: *Int. J.ProductionEconomics* 176, pp. 98–110.

Wiendahl, H.-P., A. Slaouto, and R. Nickel (2008). “Proactive supply chain management in the forging industry”. In: *Prod. Eng. Res. Devel.* 2008.2, pp. 425–430.

An Adaptive Supply Chain Cyber Risk Management Methodology

Stefan Schauer[1], Martin Stamer[2], Claudia Bosse[2], Michalis Pavlidis[3], Haralambos Mouratidis[3], Sandra König[1], Spyros Papastergiou[4]

1 – AIT Austrian Institute of Technology

2 – Fraunhofer CML

3 – University of Brighton

4 – University of Piraeus Research Center

Maritime information infrastructures have developed to highly interrelated cyber ecosystems, where ports as well as their partners are connected in dynamic Information and Communication Technology (ICT)-based maritime supply chains. This makes them open and vulnerable to the rapidly changing ICT threat landscape. Hence, attacks on a seemingly isolated system of one business partner may propagate through the whole supply chain, causing cascading effects and resulting in large-scale impacts. In this article, we want to present a novel risk management methodology to assess the risk level of an entire maritime supply chain. This methodology builds upon publicly available information, well-defined mathematical approaches and best practices to automatically identify and assess vulnerabilities and potential threats of the involved cyber assets. This leads to a constantly updated risk evaluation of each business partner's cyber assets together with their cyber interconnections with other business partners. The presented risk management methodology is based on qualitative risk scales, which makes the assessment as well as the results more intuitive. Furthermore, it enables a holistic view on all of the integrated ICT-systems as well as their interdependencies and thus can increase the security level of both a whole supply chain and every participating business partner.

Keywords: IT security; cyber risk management; cyber risk assessment; maritime supply chains

1 Introduction

For an organization, participating in a maritime supply chain implies not only the need to cooperate with other stakeholders at business level, but due to the ongoing digitalization also to set up interfaces in their information and communication technology (ICT) infrastructure for the ICT systems of their business partners. Hence, these supply chains have become highly interrelated cyber ecosystem, where the complexity and degree of networking of connected digital assets beyond company borders increases. Nevertheless, every data interface also represents a potential threat in form of a possible entry point for unplanned access to the networks and the systems located behind it.

A global study among risk managers and risk experts rated cyber incidents as the third highest business risk worldwide for all sectors and are expected to become the highest business risk in the future. In Europe, cyber risks are rated already as the second highest and in Germany as the highest business risk (Allianz Global Corporate & Specialty SE, 2017).

So far, the number of disclosed cyber incidents in the transportation sector is not very high and thus can be considered to be even smaller in maritime supply chains (Verizon, 2017). However, companies might not report every attack due to fears of reputational damage or - even worse - the attacks weren't noticed due to a lack of awareness and knowledge (Wingrove, 2017; Kotchetkova, 2015). Considering the damage potential, vessels and ports might become an appealing target for attackers in the future. The following incidents from the past illustrate the bandwidth of possibilities: (a) Drugs were hidden in containers and these containers were misled without early recognition (Bateman, 2013); (b) Customs systems were shut down, stopping operations for hours, probably to extort ransom (Port of Rotterdam, 2016); (c) Disruption of the GPS-signal stopped operations of vessels as well as of terminal cranes that store and locate containers basing on GPS for the same reason (Wagstaff, 2014; Scott, 2015; Hayes, 2016); (d) Piracy attacks use AIS-signals to identify vessels and hack into the shipping companies systems to identify their loaded goods (Allianz Global Corporate & Specialty SE, 2016); (e) Global ransomware campaign known as "WannaCry" and detected on May 12, 2017, affected various organizations with tens of thousands of infections in over 150 countries (US-CERT, 2017a).

Just a couple of weeks after the "WannaCry" attack, on June 27, 2017, another major global cyberattack (at some point linked to the existing ransomware "Petya", but later on due to its additional features also referred to as "NotPetya") was launched, using among other attack vectors the same exploit as ”WannaCry” (US-CERT, 2017b; Fox-Brewster, 2017). It exploited a vulnerability in a Ukrainian tax preparation software update mechanism to propagate and attack entire networks (e.g. Cimpanu, 2017). Besides several Ukrainian ministries, banks and metro systems, large companies became also victim of the attack. Among many others, Beiersdorf AG, A. P. Moller-Maersk Group, Merck Sharp & Dohme (e.g. Holland, 2017) and India's largest container terminal JNPT (e.g. PTI, 2017) were affected and, as a consequence, had to deal with business interruptions. The malware's attack path leading from a Ukrainian software update to several international company networks shows how malware can propagate among the connected ICT systems in supply chains.

Due to these incidents, the general awareness for the need of cyber security and cyber risk management increases and will rise further with every new mayor security incident. Nevertheless, state-of-the-art risk management methodologies for maritime environments pay limited attention to cyber-security and do not adequately address security processes for international supply chains. Motivated by these limitations, we introduce the MITIGATE methodology, a novel risk management approach, which will empower stakeholders' collaboration for the identification, assessment and mitigation of risks associated with cyber-security assets and supply chain processes. This collaborative system will boost transparency in risk handling, while enabling the generation of unique evidence about risk assessment and mitigation.

The paper is structured as follows: Section 2 presents general regulations and standards for port security. Section 3 provides a short overview on the MITIGATE project while one of the project's main outputs, the MITIGATE risk management methodology, is described in Section 4. The key concepts of the MITIGATE methodology are sketched in Section 5 followed by a discussion, while section 7 concludes the paper.

2 Regulations and Standards for Port Security

ICT systems of ports are classified as “Critical Information Infrastructures” (CII), because ports are of crucial importance for the unrestricted supply, trade and economy of a country. The EU adopted in July 2016 the Network and Information System (NIS) Directive (EU, 2016). The directive aims to reach a common level of security for NIS in the EU. This process will be supported by the European Union

Agency for Network and Information Security (ENISA) and protected by Computer Security Incident Response Teams (CSIRT) all over Europe.

There are already several security guidelines in place, e.g., from the Baltic and International Maritime Council BIMCO (BIMCO, 2017). They provide effective advice, and awareness-rising posters for the use on board showing the need for security measures. Further, they indicate how to avoid the biggest part of incidents by giving striking rules for the use of passwords and private communication devices. The International Maritime Organization (IMO) issued the "Interim Guidelines on Maritime Cyber Risk Management" in 2016 (IMO, 2016) and the U.S. promotes "Information Sharing and Analysis Organizations" (ISAO), e.g., the "Maritime & Port Security Information Sharing and Analysis Organization" (MPS-ISAO, 2017). Finally, the International Association of Classification Societies (IACS) in shipping reacts to cyber threats with a "Cyber Systems Panel" that was installed in 2016 (IACS, 2015). The focus of this panel lies on the early development of cyber resilient onboard systems.

Beside these guidelines, there are also several standards and regulative which address security and cyber security issues in maritime supply chains. Among them, the most important is the International Ship and Port Facilities Security (ISPS) Code (International Maritime Organization, 2003). The ISPS Code is a comprehensive set of measures to enhance the security of ships and port facilities, focusing mainly on topics from the field of physical security and object protection. Hence, a major drawback is the lack of specific tools, distinct measures or general role descriptions tailored to the ICT security for port infrastructures. The main objectives of the ISPS-Code with regards to ICT infrastructures are to ensure that security communication is easily available and to prevent unauthorized deletion, destruction or amendment of the security plans. Security plans may be saved in an electronical format and therefore need to be protected.

An international standard specifically tailored to the field of ICT security is the ISO/IEC 27001:2013 (International Standardization Organization, 2013). The ISO/IEC 27001 is a commercial standard, representing a collection of best practices and guidelines, describing how to establish, implement, maintain, monitor and improve an Information Security Management System (ISMS). The standard is generic in a way that the specified ISMS is applicable to organizations of various types, sizes as well as different industries and markets. It should be noted that ISO/IEC 27001 is actually not a risk management methodology, but rather a compliance standard, reporting a list of controls for good security practices and the requisites that an existing method should have to be standard-compliant. Specifically, it provides generic requirements that the risk analysis and management needs to fulfill and references the ISO/IEC 27005 (International Standardization Organization, 2011) (and further the ISO 31000 (International Standardization Organization, 2009)) as a possible risk management methodology.

Although the ISO/IEC 27001 is applicable to several domains, the transportation and logistics industry has introduced a common security management standard, the ISO 28001:2007 (International Standardization Organization, 2007). Whereas the ISO/IEC 27001 or the ISPS are focused on a single organization, the security of the overall supply chain is the main objective of the ISO 28001. Therefore, the standard includes the specific requirements to improve the security of all aspects of the supply chain, including financing, manufacturing, information management and the facilities for packing, storing and transferring goods between modes of transport and locations. As a specialty of the ISO 28001, all partners involved in the supply chain need to sign a security declaration specifying their currently implemented security measures to ensure a common security level over the whole supply chain.

3 MITIGATE Project

As described in the previous Section, there are several standards and guidelines at hand to prepare for cyber attacks and incidents. Nevertheless, a framework dedicated to the assessment and management of cyber risks of maritime supply chains has not been developed, yet. The ICT infrastructure of ports is particularly vulnerable, due to comprising hard- and software assets of the companies engaged in transport and goods handling in the maritime supply chain. Ports are located at the interface of information flows from many different users and countries, which have to offer access and exchange capabilities for digital information. However, all these interfaces also represent possible entry points for attackers. The ongoing digitalization will result in even more complex and a higher degree of networked ICT systems and so will the number of electronic interfaces to business partner systems in supply chains increase, which cannot be supervised and controlled by the single company.

In order to ensure that these processes and interconnections don‘t allow malware to shut down operations or allow manipulation of data for illegal purposes, a solution to identify threats along the supply chain and beyond company boundaries is urgently needed. The H2020 project MITIGATE (MITIGATE, 2016) is looking in particular into security issues within the supply chain and aims at providing tailored solutions for these problems. MITIGATE will introduce, integrate, validate, evaluate and commercialize a risk management system for port infrastructures, which will be able to deal with port CIIs and ICT systems, as well as their impact on dynamic maritime supply chains. MITIGATE will emphasize the collaboration of various stakeholders in the identification, assessment and mitigation of risks associated with cyber-security assets and international supply chain processes. This collaborative approach will boost transparency in risk handling by the various stakeholders, while it will also generate unique evidence about risk assessment and mitigation.

The collaborative approach of the project will be empowered by the MITIGATE Open Simulation Environment enabling the participants to model, design, execute and analyze attack-oriented simulation experiments using novel simulation processes. Particular emphasis will be laid on the estimation of the cascading effects, as well as on the prediction of future risks (based upon common metrics across sectors). Relying on evidence–based simulations, port operators, decision makers and other stakeholders will be able to select cost effective countermeasures and compile holistic port security policies going beyond the ports' CII isolated domain to ensure the ports' supply chain security.

Furthermore, the tools will be equipped with real-time decision support systems, which will aim at automating the process of estimating risk and enacting risk mitigation measures. MITIGAGE will integrate open source intelligence data (including data from social networks and crowd-sourcing) towards enhancing its threat assessment and prediction functionalities. At the heart of the MITIGATE system will be a range of mathematical instruments, which will be used for threat and vulnerability analysis, as well as for the assessment of contingency plans and their cost-effectiveness.

4 Risk Management Methodology

As a core result of the MITIGATE project, the MITIGATE Risk Management Methodology has been developed. It aims at estimating the cyber risks for all assets of all business partners involved in a maritime supply chain service (SCS) and represent the basis for the MITIGATE system. The MITIGATE methodology is compliant with

SCS Analysis	Cyber Threat Analysis	Vulnerability Analysis	Impact Analysis	Risk Assessment	Risk Mitigation
S1.1:Goals & Objectives	**S2.1**: SCS Cyber Threat Identification	**S3.1**: Identification of Confirmed Vulnerabilities	**S4.1**: Individual Asset Impact Assessment	**S5.1**: Individual Asset Risk Assessment	**S6**: Risk Mitigation
S1.2: Business Partners	**S2.2**: SCS Cyber Threat Assessment	**S3.2**: Identification of Unknown Vulnerabilities	**S4.2**: Cumulative Impact Assessment	**S5.2**: Cumulative Risk Assessment	
S1.3: Modelling		**S3.3**: Individual Vulnerability Assessment	**S4.3**: Propagated Impact Assessment	**S5.3**: Propagated Risk Assessment	
		S3.4: Cumulative Vulnerability Assessment			
		S3.5: Propagated Vulnerability Assessment			

Figure 1: Overview of the different steps of the MITIGATE methodology

the main standards for port security, the ISPS Code (IT Section), ISO 27001 and ISO 28001, which have been briefly described in the previous Section 2. Accordingly, the six steps of the methodology (cf. Figure 1) represent the main steps also described in these standards. In the following, we will present a high-level overview on the different steps of the methodology going into detail on the central features later on in Section 5.

4.1 SCS Analysis

In this first step, the scope of the risk assessment is defined. Therefore, the business partners involved in the SCS under examination are identified. All the business partners agree on the goals and the desired outcome of the risk assessment. Further, the SCS under examination is decomposed and inspected in detail by the business partner's risk assessors who initiated the risk assessment. They identify the participants of the SCS involved from their perspective, i.e., within their organizations.

For each participant of the risk assessment, the main cyber and/or physical processes (i.e., controlled/monitored by a cyber system) that comprise the examined

SCS are collected. The MITIGATE methodology is focusing in particular on the interdependencies among these cyber assets. Therefore, these interdependencies are further classified based on different types (e.g., whether they are installed on the same system, communicating of network interfaces, etc.) describing the relationship between the cyber assets in more detail.

The SCS analysis results in a list of all business partners together with their cyber assets relevant for the SCS. Further, a graph of all cyber assets connected based on their interdependencies is created.

4.2 SCS Cyber Threat Analysis

Based on the list of cyber assets created in the first step, all potential threats related to these cyber assets are identified in the second step of the MITIGATE methodology. Due to today's rapidly changing threat landscape, the list of threats needs to be as exhaustive and up-to-date as possible. To achieve that, the MITIGATE methodology foresees the integration of multiple source of information, i.e., online threat repositories like the National Vulnerability Database (NVD)(NIST, 2017), crowd sourcing and social media as well as the business partners' experts. This makes the methodology highly adaptive to novel attack strategies and attacker behavior. The multitude of different data sources helps to increase the quality of the whole risk assessment.

When the list of relevant threats is established, the likelihood of occurrence is estimated for each of them. Also for this step, various sources of information are combined: information from online repositories and social media is taken into consideration as well as historical data and expert opinions. Instead of just use one of these sources (e.g., relying only on historical data or expert opinions), this approach offers the advantage of integrating a more diverse and complete overview on the topic. Thus, the assessor obtains a more realistic estimation of the threat likelihood. The resulting likelihoods are expressed using a semi-quantitative, five-tier scale and all the gathered information is integrated. Finally, a Threat Level (TL) based on this likelihood is assigned to each threat.

4.3 Vulnerability Analysis

Similar to the identification of threats in the previous step, in this step a list of vulnerabilities of the cyber assets of the SCS under examination is compiled. In the context of the MITIGATE methodology, a vulnerability is understood as a defective state of a cyber assets due to a poor configuration, the lack of security patching, etc. A threat can manifest in the SCS by exploiting a vulnerability of one of the involved cyber assets.

The MITIGATE methodology differences between two main types of vulnerabilities: confirmed vulnerabilities and potentially unknown or undisclosed vulnerabilities. In more detail, vulnerabilities which are already know in the community and are listed in online repositories or by specific Computer Emergency Response Teams (CERTs) are understood as confirmed vulnerabilities. On the other hand, there are vulnerabilities in software systems which are not publicly known, yet. Such unknown or undisclosed vulnerabilities are more dangerous since security experts are not aware of them but they can be (easily) exploited by adversaries.

A core feature of the MITIGATE methodology is to take these unknown and/or undisclosed vulnerabilities into account. In this context, the data coming from various information sources (online repositories, social media, expert knowledge, etc.) is collected and processed to estimate the existence of unknown vulnerabilities. In more detail, the analysis is carried out over all time scales in the available dataset (e.g., by empirically characterizing the distribution of a vulnerability's lifespan) or determining the number of vulnerabilities publicly announced for a specific period of time (e.g., using the rate of vulnerability announcements in the NVD).

To characterize both confirmed and unknown/undisclosed vulnerabilities within one methodology and make them comparable, the Common Vulnerability Scoring System (CVSS) (Mell and Scarfone, 2007) is applied. For each vulnerability, the Individual Vulnerability Level (IVL) is specified by assessing the Access Vector, Access Complexity and Authentication. The scores for these three values are coming from the online database NVD and are mapped onto a qualitative, five-tier scale for further processing. The details on this mapping are given in section 5.1.

Additionally, the MITIGATE methodology is not only looking at the immediate effects of an attack exploiting a specific vulnerability but is also taking the respective cascading effects into account. Therefore, the concepts of a Cumulative Vulnerability Level (CVL) and a Propagated Vulnerability Level (PVL) are introduced. They are described in detail in the following Section 5.2. Accordingly, the vulnerability analysis results in a list of all vulnerabilities together with their respective IVL, CVL and PVL.

4.4 Impact Analysis

After the vulnerability analysis done in the previous step, the MITIGATE methodology is also looking at the potential impact an exploitation of these vulnerabilities might have. To stay consistent with the vulnerability analysis, the CVSS (more specifically, the three security criteria Confidentiality, Integrity and Availability) is applied for assessing the impact. Accordingly, the scores for the security criteria are also mapped onto the same qualitative, five-tier scale as the vulnerabilities (cf. Section 5.1).

Furthermore, the notion of cascading effects is carried on for the impact analysis, resulting in the concepts of Individual Impact Level (IIL), Cumulative Impact Level (CIL) and Propagated Impact Level (PIL). Details on these impact levels are also discussed in further detail in Section 5.2.

4.5 Risk Assessment

The risk assessment in the MITIGATE methodology is loosely based on the general approach risk = likelihood $\times$ impact (Oppliger, 2015). Hence, in our context the threat level (as described in Step 2, Section 4.2), vulnerability level (as described in Step 3, Section 4.3) and impact level (as described in Step 4, Section 4.4) contribute to the risk level. Further carrying on the notion of cascading effects, the MITIGATE methodology describes three risk levels: Individual Risk Level (IRL), Cumulative Risk Level (CRL) and Propagated Risk Level (PRL). This leads to the following formula

$$IRL = TL \times IVL \times IIL$$

for the Individual Risk Level; the other two risk levels (CRL and PRL) are computed accordingly. The overall result is then again mapped onto a qualitative, five-tier scale.

4.6 Risk Mitigation

In the final step of the MITIGATE methodology, the main results of the risk assessment are compared against specific thresholds, which have been set and agreed by all business partners. If some of the results exceed these predefined thresholds, additional security controls need to be implemented by the business partners and by the SCS (as a whole) to lower the respective risk levels. To identify the best choice of mitigation actions out of a set of possible controls, a game-theoretic approach is applied. This represents a mathematically sound method to find a way to minimize the expected damage caused by an attack that exploits multiple vulnerabilities.

To formalize the game, the possible actions taken by the adversary (i.e., a malicious party performing an attack) and the defender (i.e., all business partners in the supply chain) need to be identified. Any combination of these attack and defense strategies yields a particular damage (i.e., the risk level), which is interpreted as the respective payoff for this combination. Minimizing over all these damages (i.e., the game's payoff matrix) leads to the three main outcomes of this step: an optimal attack strategy, an optimal defense strategy and the maximum risk level for the case the attacker and defender both follow their optimal strategies.

The optimal defense strategy indicates which mitigation actions should be chosen by all the business partners to minimize the damage to the entire SCS. Due to the mathematical basis of game theory, it can be shown that even if the adversary deviates from the optimal attack strategy, the business partners don't have to change their defensive strategy; a deviation by the adversary only manifests in a lower maximum risk level as long as the defender plays his optimal strategy. We describe this approach in more detail in section 5.3.

5 MITIGATE Key Concepts

The MITIGATE methodology builds on three major concepts for the assessment of the cyber risks within the SCS, which also represent the main research results of the MITIGATE project. Further, the combination of these concepts also represents the main difference and advantage of the MITIGATE methodology over existing solutions. In the following, we will describe these three concepts in more detail.

AV	Local			Adjacent			Network		
Auth \ AC	High	Medium	Low	High	Medium	Low	High	Medium	Low
Multiple	VL	VL	L	L	L	M	M	M	H
Single	VL	L	M	L	M	H	M	H	VH
None	L	M	M	M	H	H	H	VH	VH

Figure 2: Mapping of the CVSS metric "Exploitability" onto the IVL

5.1 Semi-Automated Vulnerability Analysis

As already pointed out in previous sections, threats and attacks on cyber systems have evolved drastically over the last years. An increasing number of more and more complex attacks have been carried out and large companies as well as critical infrastructures have fallen victim to those attacks. One major reason for that is the large number of vulnerabilities in software systems, which can be exploited by malicious parties to circumvent security systems and infiltrate an organization's infrastructure. As mentioned in Section 4.3, unknown vulnerabilities are the most critical ones in this context, because neither the users nor the creators of a software system are aware of their existence.

Most of today's risk assessment methodologies and frameworks are not able to keep up this speed of evolving attacks and are not aware of the vulnerabilities within examined systems. The MITIGATE methodology is able to adapt to this fact and to build the risk assessment on top of a constantly updated vulnerability database, i.e., the NVD. It is maintained by the National Institute of Standards and Technology (NIST) (NIST, 2017) and updated frequently with the most current information on numerous software systems. Further, the NVD applies the CVSS to assess each vulnerability, providing an estimation of a specific vulnerability's relative importance, which further allows setting up a prioritization later on.

As described in Section 4.2 above, all the assets relevant for a specific SCS are collected during Step 2 of the MITIAGTE methodology. In addition, information on existing vulnerabilities is imported from the NVD on a daily basis and checked against the identified assets. This results in a list of assets together with the latest version of their vulnerabilities. Furthermore, the CVSS scoring given in the NVD is mapped onto a five-tier scale, ranging from "Very Low" to "Very High". The resulting score represents the above mentioned Individual Vulnerability Level (IVL) and is automatically assigned to every vulnerability of every asset in the SCS (cf. Figure 2).

A \ C / I	None			Partial			Complete		
	None	Partial	Complete	None	Partial	Complete	None	Partial	Complete
None	VL	VL	L	L	L	M	M	M	H
Partial	VL	L	M	L	M	H	M	H	VH
Complete	L	M	M	M	H	H	H	VH	VH

Figure 3: Mapping of the CVSS metric ”Impact” onto the IIL

Since the CVSS also estimates the consequences exploiting a specific vulnerability may have on the Confidentiality (C), Integrity (I) and Availability (A) of the underlying asset, this information is integrated into the Individual Impact Level (IIL) by applying a similar mapping (cf. Figure 3).

Furthermore, also currently unknown vulnerabilities can be defined in the MITIGATE methodology for each asset. As already mentioned in Section 4.3 above, this information is usually found by involving expert knowledge or interpreting contributions in news feeds or social media. The MITIGATE methodology supports this activity by an automated search of the respective online sources and highlighting potential relevant topics. Nevertheless, the assessment has to be carried out by an expert but can be done using the CVSS metrics (or the five-tier scale) as for to the known vulnerabilities. In this way, information coming from different sources can be easily integrated into the same assessment process.

5.2 Cumulative and Propagated Risks

When looking at the vulnerabilities identified in the beginning of Step 3 (cf. Section 4.3), we have to be aware that the exploitation of one vulnerability may just be the entry point of an adversary into a business partner’s infrastructure. For example, using the enhanced access rights gained by the exploiting a specific vulnerability, an adversary might be able to further navigate through the organization’s asset network towards another (and maybe more profitable) target. In particular, this is the case for Advanced Persistent Threats (APT)s. Therefore, the following two views also need to be considered in the analysis of a specific vulnerability: on the one hand, what are the possible ways (paths in the asset network) to reach that vulnerability instead of attacking it directly (if that is possible at all). On the other hand, after exploiting one vulnerability, what are the other possible vulnerabilities an adversary is able to reach (e.g., due to additional privileges or access to other assets).

The MITIGATE methodology accounts for both ideas by introducing the concepts of Cumulative Vulnerability Level (CVL) and Propagated Vulnerability Level (PVL). The goal of the CVL is to accurately reflect the exploitation level of the vulnerabilities by taking into consideration the IVL and the context within which these vulnerabilities appear (i.e., the assets' interdependencies). In other words, the CVL measures the likelihood that an attacker can successfully reach and exploit a vulnerability, given a specific path in the asset network. Such a path describes the list of sequential vulnerabilities on different assets that arise from consequential multi-steps attacks.

Whereas the CVL focuses on all possible attack chains concluding into the same target point, the PVL inspects the likelihood that an attacker can penetrate a network up to some specific depth. In other words, the PVL takes all possible paths of sequential vulnerabilities of a specific length into account, starting from one particular vulnerability.

Analogously to the CVL and PVL, the Cumulative Impact Level (CIL) and Propagated Impact Level (PIL) are defined. As indicated by the naming, the only difference is that in this case the potential impact of exploiting a specific vulnerability is assessed. Carrying on as already mentioned in Step 5 of the MITIGATE methodology (cf. Section 4.5), both concepts of vulnerability and impact are combined to result in the respective notions of risk. Hence, the MITIGATE methodology outputs a Cumulative Risk Level (CRL) and a Propagated Risk Level (PRL) together with the IRL already mentioned in Section 4.5.

5.3 Attack Paths Discovery

Essential element of risk management, and of the MITIGATE methodology, is the mitigation of risks through the identification of appropriate security controls. To this end, attack paths are a valuable tool to business partners, illustrating paths an attacker can use to reach a particular cyber asset. It can support the analysis of risks to a specific cyber asset that may not be the entry point of an attack and support the examination of possible consequences of a successful attack. Moreover, the attack paths support the identification of appropriate security controls by providing knowledge about attributes that make an attack possible. The generated attack paths can answer 'what-if' questions regarding the security implications of configuration changes to assets, such as patching a specific asset. Furthermore, they can reveal which attacks can be performed by highly skilled attackers and well-funded attackers and which attacks can be performed by low skilled attackers.

The MITIGATE methodology includes an algorithm to discover attack paths. In particular, it examines how an attacker can exploit identified cyber asset vulnerabilities in order to perform undesired actions. For every attack, a set of related weaknesses (CWE) and vulnerability types are defined. It is assumed that to perform this kind of attack the attacker must have access to an asset that has one or more vulnerabilities that are compatible with either the weaknesses or the type defined. Attack paths are then modelled by employing attack graphs. Each node in the graph represents a combination of asset and vulnerabilities that an attacker can exploit. Each edge represents the transition of an attacker from one asset to another.

The algorithm requires as input a physical network topology, an asset configuration, a set of entry points and target points, and an attacker's profile. In particular, the network topology includes a list of cyber assets and their relationships. For example, an asset may be installed on another asset or it just communicates with another asset. The asset configuration includes information about a particular asset. For example, the name of the asset, an id, the business partner to which this asset belongs, its vulnerabilities, and attributes from the CVE repository, such as access complexity and access vector. The entry point and the target points are specific cyber assets on which a business partner wants to focus on. The attacker's profile includes information about the assumed attacker, such as the attacker capability, which is the counterpart to a vulnerability's access complexity and the attacker location, which is the counterpart to a vulnerability's access location. The attackers profile is used to induce whether a particular attack can exploit an asset's vulnerability.

The output of the algorithm is a list of attacks paths. Each attack path contains an ordered list of cyber assets that an attacker with a particular attacker's profile can successfully compromise by exploiting their vulnerabilities. Each cyber asset in the attack path can be used as a stepping stone to an attack to the next cyber asset. A business partner must be able to locate all potential attack paths into the network and prevent attackers from using it. Business partners can hypothesize new 'zero-day" vulnerabilities of cyber assets, evaluate the impact of changing configuration settings, and determining the security effectiveness of adding new security controls. The identification of an optimal set of security controls, which receives as input the generated attack paths, is described in the next section.

5.4 Game-Theoretic Risk Minimization

Besides identifying and assessing the vulnerabilities of assets and thus obtaining a risk estimation based on latest threat information, mitigating these risks is an essential part of the MITIGATE methodology. Whereas other approaches only offer guidance on which mitigation actions to choose, the MITIGATE methodology applies a game-theoretic framework to identify the optimal set of mitigation actions.

The game is setup as a two-player zero-sum game, applying a minimax-approach (Maschler, Solan and Zamir, 2013). To be more specific, the game describes the combating situation between two players (in our case an adversary and the defender, i.e., security officer) where each player tries to optimize his payoff. In a zero-sum game, the gain of one player represents, at the same time, the loss of the other player, which describes the real-life situation between an adversary and the defender quite well. Both players have a set of strategies they can follow and each strategy results in a specific profit for each player. These profits are collected in the payoff matrix and the goal is to minimize the maximum profit (i.e., minimax-approach) of the adversary. Thus, the strategies for both the adversary and the defender are the central parts in the MITIGATE methodology. The adversary's strategies are defined by the paths through the asset network, which the adversary is able to take to reach a specific vulnerability. These paths have been defined in Step 3 (Section 4.3). The defender's strategies are given by the respective security measures a business partner is able to implement. These countermeasures may come from the business partner's experience or can be deduced from the information stored in the NVD. Such a defense strategy could be to do spot checking or patching of a specific asset (i.e., closing a specific vulnerability).

Each combination of an attack and a defense strategy defines a scenario with a specific payoff for both the adversary and the defender. In our context, this payoff is the potential damage caused by the attack (represented by the IIL, CIL and PIL). The adversary wants to maximize this damage; the defender wants to minimize it. Since both the CIL and PIL representing the damage are based on the potential paths an adversary can take in the asset network, the effect of a defense strategy

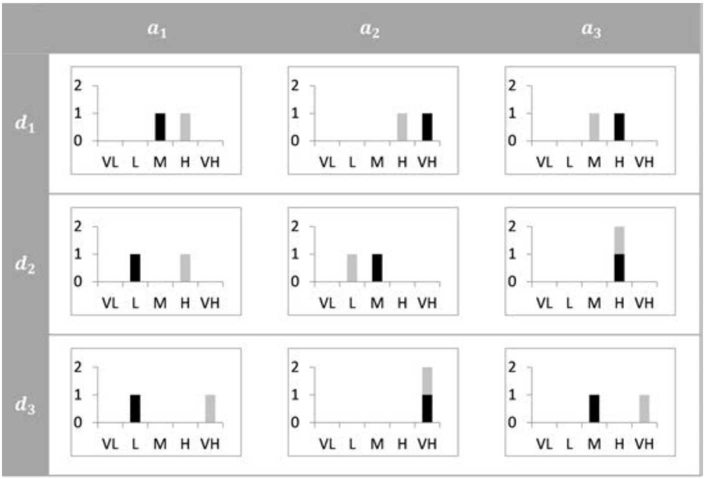

Figure 4: Example of a payoff matrix for the game with attack strategies a_1 to a_3 and defense strategies d_1 to d_3 (cf. Schauer et al., 2016).

is modeled by closing some vulnerabilities and thus eliminating some of these paths. In general, every scenario will consist of multiple paths, each one causing a specific damage. The best way to represent the collection of all these damages without losing any information is to use a histogram (Rass, König and Schauer, 2015).

The payoffs for all scenarios are collected in the payoff matrix, which is used to evaluate the game (cf. Figure 4 for an example). Since we are using histograms as payoffs, we are going beyond standard game theory and have to apply a novel framework (Rass, 2015; Rass, König and Schauer, 2015) to solve the game. The game yields the three main outputs of the risk minimization step: the first is an optimal attack strategy, i.e., a selection of the identified attack strategies, together with a probability for each strategy to be played. Following these strategies causes the maximum amount of damage to the infrastructure (worst case). The second result is an optimal defense strategy, i.e., a subset of all possible security measures together with a probability for each strategy. Implementing this strategy protects the infrastructure against the optimal attack strategy. The third result is maximum damage (characterized by the maximum risk level) an adversary can cause, if the optimal attack strategy and the optimal defense strategy are implemented.

6 Discussion

The MITIGATE risk management methodology, as presented in the previous sections, provides a structured approach for maritime information infrastructures to be prepared for today's rapidly changing threat landscape and the associated challenges. Due to the automated integration of publicly accessible information on threats and vulnerabilities, the estimation of potential risks within the infrastructure is updated on a daily basis. Hence, the methodology is able to adapt quickly to novel threats or incidents and deliver an accurate risk assessment.

The collection and processing of alternative information sources (e.g., social media), as sketched in Section 4.3, allows to include also possible future (i.e., currently unknown) vulnerabilities into the risk assessment. Although this is an integrated feature of the MITIGATE methodology, the expert knowledge of a risk officer is still required to evaluate the gathered data. Nevertheless, this marks an additional step towards an adaptive risk management framework suitable for todays' complex and highly dynamic threats.

The application of a game-theoretic approach to identify the optimal mitigation actions represents an additional benefit of the MITIGATE methodology over other methodologies and frameworks in this field. Whereas generally the question which mitigation actions to implement in the end is often left to the risk office, our methodology outputs an optimal set of security measures to be implemented. Moreover, the methodology indicates, how often (i.e., at which frequency) the respective actions have to be carried out.

Nevertheless, the MITIGATE methodology strongly relies on existing information about the infrastructure of an organization. In particular, the information about the setup of the supply chain service and about the involved assets gathered in the first two steps (cf. Section 4.1 and Section 4.2) needs to be as exhaustive and as complete as possible. This information can be taken from network scanning tools, existing documentation or expert knowledge, but is created outside of the methodology. Additionally, the set of available mitigation actions also needs to be as accurate and complete as possible. Only in that case, all scenarios possible in real life are evaluated in the game and the resulting defense strategy will reflect a realistic setting. In general, the quality of the results heavily depends on the quality of this information serving as input to the methodology.

Over all, the MITIGATE methodology has the ability to increase the security and risk awareness not only within ports or other maritime information infrastructures but also among the various business partners involved in maritime supply chains. In the end, this is a first - and maybe the most important - step to effectively and persistently raise the security level in these organizations.

7 Conclusion

Risk management is a core duty of maritime information infrastructures, in particular when considering the rising number of security incidents all over the world. The MITIGATE methodology represents a supply chain risk management framework going beyond state-of-the-art standards and guidelines. To this end, it integrates an effective, collaborative, standards-based risk management approach, which considers up-to-date information on all threats and vulnerability arising from the supply chain, including threats associated with ports' interdependencies and their potential cascading effects.

Although the MITIGATE methodology integrates several open intelligence sources and thus can quickly adapt to upcoming threats, the results are only as good as the input data. Especially when it comes to the interdependencies between the cyber assets within and among business partner's organizations, expert knowledge is required to model these relations correctly. Additionally, the experts need to identify a level of abstraction when analyzing the cyber assets within their organization since not all cyber assets within the organization will be relevant for the SCS and thus not all of them need to go into the analysis.

The MITIGATE methodology is currently being implemented in a collaborative system (http://mitigate.euprojects.net/) to enable all business partners within a SCS to perform their cyber risk assessment in context of the entire supply chain. By the end of the MITIGATE project, a large number of port operators, maritime stakeholders and security experts will have been engaged in the process of evaluating the capacity of the MITIGATE methodology and system.

Based on this evaluation, future research in this field will examine the question, how collaborative aspects of the methodology can be facilitated and strengthened as well as how small companies without specific IT related knowledge can be further supported in the security management of their cyber assets.

Acknowledgements

We would like to thank our partners in the MITIGATE project, who also contributed to the development of the MITIGATE methodology, in particular Nineta Polemi,Thanos Karantzias, Christos Douligeris and Evangelos Rekleitis.

Financial Disclosure

This work is supported by the European Commission's Project No. 653212, MITIGATE (Multidimensional, IntegraTed, rIsk assessment framework and dynamic, collaborative Risk ManaGement tools for critical information infrAstrucTurEs) under the Horizon 2020 Framework Programme (H2020-DS-2014-1).

References

Allianz Global Corporate & Specialty SE (2016). *Safety and Shipping Review 2016.*

Allianz Global Corporate & Specialty SE (2017). *Allianz Global Risk Barometer Top Business Risks 2017.*

Baltic, T. and I. M. C. (BIMCO) (2017). *The guidelines on cyber security onboard ships. Version 2.0*.

Bateman, T. (2013). *Police warning after drug traffickers' cyber-attack.*

Cimpanu, C. (2017). *Petya Ransomware Outbreak Originated in Ukraine via Tainted Accounting Software*.

Classification Societies (IACS), I. A. of (2015). *IACS Council 72 Press Release 14 Dec 2015 - IACS*.

(EU), E. U. (2016). *Directive (EU) 2016/1148 of the European Parliament and of the Council of 6 July 2016 concerning measures for a high common level of security of network and information systems across the Union*.

Fox-Brewster, T. (2017). *Petya Or NotPetya: Why The Latest Ransomware Is Deadlier Than WannaCry*.

Hayes, G. (2016). *GPS can be jammed and 'spoofed'–just how vulnerable is it?*

Holland, M. (2017). *Rückkehr von Petya – Kryptotrojaner legt weltweit Firmen und Behörden lahm*.

(IMO), I. M. O. (2016). *Interim guidelines on maritime cyber risk management.*

International Maritime Organization, ed. (2003). *ISPS Code: International Ship and Port Facility Security Code and SOLAS amendments adopted 12 December 2002*. 2003 ed. OCLC: ocm51823054. London: International Maritime Organization.

International Standardization Organization (2007). *ISO 28001: Security management systems for the supply chain - Best practices for implementing supply chain security, assessments and plans - Requirements and guidance*. English Version. Geneva, Switzerland.
International Standardization Organization (2009). *ISO 31000: Risk Management – Principles and Guidelines*. English Version. Geneva, Switzerland.
International Standardization Organization (2011). *ISO/IEC 27005: Information technology - Security techniques - Information security risk management*. English Version. Geneva, Switzerland.
International Standardization Organization (2013). *ISO/IEC 27001: Information technology - Security techniques - Information security management systems - Requirements*. English Version. Geneva, Switzerland.
Kotchetkova, K. (2015). *Maritime industry is easy meat for cyber criminals.*
Maschler, M., E. Solan, and S. Zamir (2013). *Game Theory*. Cambridge University Press.
Mell, P. and K. Scarfone (2007). *A Complete Guide to the Common Vulnerability Scoring System*.
MPS-ISAO (2017). *Maritime & Port Security ISAO | Operationalizing Cyber Resilience*. 2016.
Oppliger, R. (2015). "Quantitative Risk Analysis in Information Security Management: A Modern Fairy Tale". In: *IEEE Security Privacy* 13.6, pp. 18–21.
Port of Rotterdam (2016). *How the Port of Rotterdam is investing in cybersecurity.*
PTI (2017). *New malware hits JNPT operations as APM Terminals hacked globally | The Indian Express*.
Rass, S. (2015). "On Game-Theoretic Risk Management (Part One) – Towards a Theory of Games with Payoffs that are Probability-Distributions". In: *ArXiv e-prints*.
Rass, S., S. König, and S. Schauer (2015). "Uncertainty in Games: Using Probability-Distributions as Payoffs". In: *Decision and Game Theory for Security*. Lecture Notes inComputer Science 9406. London, UK: Springer, pp. 346–357.
Schauer, S., S. König, S. Rass, and M. Latzenhofer (2016). "Spieltheoretische Risikominimierung in IKT Infrastrukturen". In: *DACH Security 2016*. Klagenfurt, Austria: syssec, pp. 174–187.
Scott, L. (2015). *Protecting Position in Critical Operations*.
Standards, N. I. of and T. (NIST) (2017). *National Vulnerability Database (NVD)*.
(US-CERT), U. S. C. E. R. T. (2017a). *Alert (TA17-132A) Indicators Associated With WannaCry Ransomware*.
(US-CERT), U. S. C. E. R. T. (2017b). *Alert (TA17-181A) Petya Ransomware*.
Verizon (2017). *2017 Data Breach Investigations Report.*
Wagstaff, J. (2014). *All at sea: global shipping fleet exposed to hacking threat.*
Wingrove, M. (2017). *Ships are already under cyber attack.*

Simulation-Framework for Illicit-Goods Detection in Large Volume Freight

Lutz Kretschmann[1], Torsten Münsterberg[1]

1 – Center für Maritime Logistik und Dienstleistungen (Fraunhofer CML)

Innovative non-intrusive inspection technologies can help customs prevent illicit trade in large volume freight. Validation whether technologies fulfill their intended purpose ideally takes place under real conditions. However, constraints limit the number and type of experiments performed during such field trials. Against this background simulation offers the opportunity to evaluate improvements in detection of illicit-goods without interrupting activities on site. A discrete event simulation framework in the context of large volume freight is introduced in this paper. It provides the means to compare alternative detection architectures - combinations of different detection technologies – regarding their effectiveness in identifying illicit goods in containers while at the same time the flow of goods through security checkpoints can be analyzed. The framework is applied to an exemplary case study comparing a single device detection architecture with a two device system. Results highlight the somewhat counter intuitive logic that adding a second device to the detection architecture either reduces the overall false clear probability at the cost of a higher false alarm rate or vice versa. Further the impact that adding another layer of detection has on the flow of containers through the detection architecture and in particular on process time is discussed. Findings described here are only a first step towards building a comprehensive simulation-framework for illicit-goods detection in large volume freight. Nonetheless, they illustrate how modelling and simulation can help customs identify the optimal use of innovative detection technologies to increase overall security at EU-borders.

Keywords: maritime security; illicit trade; detection architecture; discrete event simulation;

1 Introduction

Container transport has become an essential part of global supply chains and merchandise trade connecting Europe with markets around the world. Since ports play a key role within the European transport network, maintaining a high level of port efficiency is of great importance for continued economic prosperity throughout the EU.

Besides its integral role in the movement of legitimate cargo between countries intermodal container transport is also exploited in illegal trafficking activities (WCO, 2016). Table 1 shows the main categories of illicit trade as defined by Interpol (2014). The unlawful transport of illicit goods poses a threat to security, the environment and the economy. Container shipments are potentially misused in various ways including the movement of security sensitive goods like weapons, explosives or even radioactive materials as well as illegal trade in drugs, counterfeit products and environmentally sensitive goods which negatively affects citizens directly or indirectly. Moreover illegal trade is responsible for a loss of tax revenues, causes market distortion and can be associated with damages to the environment. For a discussion of negative socio-economic impacts of illicit trade see e.g. Hintsa and Mohanty (2014). Customs, as government organizations which control and administer the movement of goods across borders, play an important role in securing international supply chains by preventing illicit trade in large volume freight. Excluding intra-European trade the total number of containers imported to the EU in 2014 was 17.5 million TEU of which the vast majority is of legitimate nature (World Shipping Council, 2017). However, the sheer number of containers moved across EU borders highlights the challenge customs face in effectively preventing illicit trafficking without interfering unduly in the legitimate flow of goods. Contributing further to the difficulty of this task is the wide variety of risk materials that need to be detected both effectively and efficiently.

It is generally agreed that physically inspecting 100 percent of containers for illicit content is not practical. Instead detection technologies play an essential role for customs administrations to meet their responsibilities. Such non-intrusive inspection (NII) technologies enable a detection of possible anomalies within the container without having to open it.

At this point image based detection technology (X-ray) plays the central role in NII for most threats. However, several research projects currently underway will result in important advancements in NII technologies for checking maritime containers and other large volume freight for anomalies in port and at land borders (see e.g.

Table 1: The main categories of illicit trade

Main sectors of illicit trade
Illicit trade in chemical, biological, radiological, nuclear and explosive material
Illicit trade in arms and weapons
Illicit trade in narcotic drugs and psychotropic substances
Illicit trade in environmentally sensitive goods
Intellectual property crime
Pharmaceutical crime
Illicit trade in excisable products
Illicit trade in cultural property

ACXIS project, 2016; C-BORD project, 2017; CRIM-TRACK project, 2014). Through these initiatives a number of new and improved NII technologies will become available which customs can deploy at their respective border crossing sites in future.

As the number of principally suitable NII systems increases, identifying the optimal set of technologies for a particular border crossing gets ever more complex and thus challenging. More choices have to be evaluated under a specific set of requirements and constraints to identify which combination of technologies has the best cost to benefit ratio. In order to support this decision process, this paper introduces a discrete event simulation framework in the context of large volume freight. It enables customs to compare combinations of different NII technologies regarding their effectiveness and efficiency to detect illicit goods. At the same time logistical constraints at a particular border crossing point can be taken into consideration and the impact of new NII systems on the flow of container through security checkpoints can be analyzed.

The remainder of this paper is structured as follows. Section 2 introduces the term detection architecture and describes how the performance of a detection architecture can be described in terms of probabilities. Subsequently Section 3 gives an overview of different approaches in literature which analyze detection architectures in order to support their design. The developed simulation-framework for illicit-goods detection is introduced in Section 4 and applied to an exemplary case study in Section 5. Concluding remarks and possibilities for future research are given in Section 6.

2 Detection Architecture

Since customs face a wide variety of possible threats and NII technologies vary in their effectiveness of detecting different threats, ideally they are integrated in a detection architecture which makes sure that each technology is used according to its particular strength. The Customs Detection Technology Expert Group defines a detection architecture as “a construction of individual detection processes into a defined structure in order to determine whether a consignment is ‘legitimate’ or ‘illicit”’ (CDTEG, 2014).

In accordance with the WCO SAFE Framework of Standards detection architectures implemented by EU customs follow a risk based approach (WCO, 2012). This means that available information and intelligence relating to a cargo shipment is used to identify potentially high-risk containers in a first screening process. These high-risk containers are selected for one or more subsequent scanning processes where further information about the content of the container is collected e.g. by means of NII equipment. In case an anomaly is sustained based on scanning results the container is unpacked in a last step and the presence of illicit goods is checked by physical inspection. If a non-conformity is found the goods are stopped or otherwise released for further transport (see figure 1).

2.1 Objectives of Detection Architecture Design

When identifying a suitable detection architecture for a specific border crossing customs have to do justice to conflicting objectives. In the case a shipment is falsely cleared and thus a threat enters the country, society has to absorb the negative socio-economic effects associated herewith. Accordingly customs have to make sure certain acceptable detection thresholds for relevant threats are met.

In order to increase the likelihood of detection, one option would be to implement a more extensive screening, scanning and physical inspection regime (in effect inspecting a larger share of containers). Alternatively thresholds could be lowered beyond which the shipment is escalated to the next detection process instead of being released (in effect already a smaller suspicion leads to further inspection). However both will result in more disruptions to the flow of legitimate shipments and increase the number of cases where scanning indicates a threat that does not exist (false alarms).

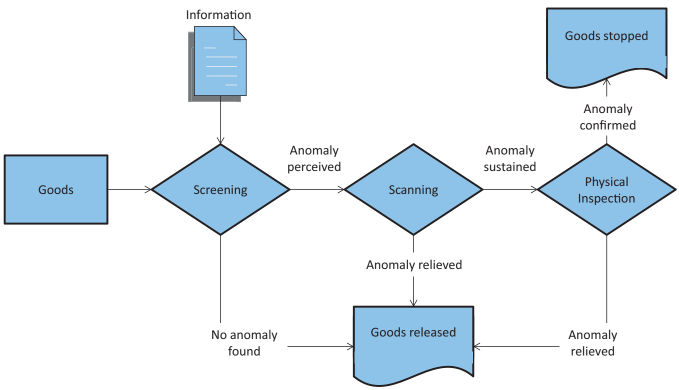

Figure 1: Detection architecture (CDTEG, 2014)

Any (unnecessary) inspection of legitimate cargo and in particular false alarms will be perceived as a nuisance by the parties involved in the transport chain. Moreover, ports with overlapping hinterlands stand in fierce competition for cargo with each other. If customs procedures in one port are extensive resulting in possible delays, generalized transport cost of moving good through this particular port will increase compared to other ports. This negatively affects the competitive position of the port and cargo is potentially shifted towards ports with lower standards (De Langen and Nijdam, 2008). Thus, customs have to maintain an appropriate level of security for one thing but also ensure that the impact of checking containers for illicit goods on the flow of freight is kept as low as possible.

2.2 Detection Capability of Detection Architectures

In order to describe the detection capability of individual scanning technologies as well as that of single or multiple-device detection architectures probability models can be used. In the simplest case an individual detection process can lead to two different outcomes: the presence of an anomaly in the container is sustained (alarm) or the presence of an anomaly in the container is relieved (clear). Following Kobza and Jacobson (1997) four possible cases have to be distinguished in this context (see figure 2).

To describe a devices capability of detecting a particular threat, probabilities of Type I and Type II errors can be used. The Type I error probability is the probability that a device raises an alarm under the condition that no threat is present in the container or P(Alarm|NoThreat). The Type II error probability on the other hand is the probability that a device does not raise an alarm under the condition

that a threat is present in the container or $P(NoAlarm|Threat)$. The lower both conditional probabilities are the better is the performance of the device.

Expected values of Type I and Type II error probabilities can be determined experimentally or, where test data is not sufficiently available, have to be estimated based on expert knowledge and information from system insiders (e.g. customs, technology providers).

The probability of a false alarm as well as the probability of a false clear is further influenced by the prevalence of non-conformities (probability that a threat is present in a container or $P(Threat)$) in the population that is being examined. Accordingly:

		Presence of threat	
		Yes	No
Response	Alarm	A true alarm – correctly detecting a threat within the container	A false alarm – detecting a threat within a container that does not exist
	Clear	A false clear – not detecting a threat within a container	A true clear – not detecting a threat within a container that does not exist

Figure 2: Possible results of detection process

$$P(FalseAlarm) = P(Alarm|NoThreat) * P(NoThreat)$$
$$P(FalseClear) = P(NoAlarm|Threat) * P(Threat)$$

Additionally a distinction between a device alarm and a system alarm is necessary for multiple device detection architectures:

- Case A – a system alarm is triggered if any device in the detection architecture raises an alarm
- Case B – a system alarm is triggered if all devices in the detection architecture raise an alarm

Probabilities of a false alarm respectively a false clear for a multiple device detection architecture under Case A and Case B are the combined conditional error probabilities of the individual devices.

3 Approaches for Analyzing Detection Architectures

Modelling and simulation methods increasingly gain acceptance in the overall security research landscape and particularly as effective tools for finding optimal detection architectures.

The primary use of discrete event simulation models, such as the simulation-framework for illicit-goods detection in large volume freight described in this paper, in this context is twofold:

— Simulate the detection performance of detection architectures

— Simulate the flow of goods through security checkpoints

Discrete event simulation can support the design process of adequate detection architectures by offering the opportunity to evaluate and assess improvements in detecting illicit goods without interrupting activities on site. Operational effectiveness, efficiency and detection performance of different system designs can be compared and analyzed according to the priorities and requirements at a specific border crossing. Moreover, as pointed out by Wilson (2005), the approach also allows determining the impact of different technology set ups on operation, logistics and cargo flow, identify bottlenecks and serves as a basis for specifying resources needed.

Several fields of research are relevant for the work presented in this paper which are briefly discussed in the following. Overall the interest in studying the design of detection architectures intensified significantly after the terrorist attacks of September 11, 2001 in New York (9/11). Understandably a large part of previous work deals with aviation and airport security as well as the detection of nuclear material smuggling as these are scenarios directly associated with terrorist threats.

Due to changes in aviation security after 9/11 explosive detection systems for 100 percent scanning of checked baggage were deployed at all US airports. Jacobson et al. (2006) apply probability modeling to evaluate the cost effectiveness of several single- and two-device explosive detection architectures at airports. While the work in this paper follows a similar approach to model the detection performance of detection architectures it focuses on a different transport system: sea ports and maritime container transport. Further it makes use of an event based simulation method which allows gaining insights into the dynamic performance of a detection architecture and thus reach a better understanding of bottlenecks and spikes in the workload

Comparable demands for a 100 percent scanning regime have also been enacted for containers entering US ports with the goal to prevent potential terrorist attacks on a port which would have devastating economic impacts (U.S. Congress, 2007). Several studies dedicated to 100 percent container scanning can be found in literature. Martonosi et al. (2005) apply a cost-benefit analysis methodology in this context to compare different scanning regimes. They conclude that switching to 100 percent scanning is not cost-effective for most scenarios unless an attack is very likely to occur. Another example can be found in the work done by Bakshi et al. (2011) who develop a discrete event simulation model. They calibrate their model using historical data from two container terminals and assess the operational impact of different inspection policies. While their work focuses on 100 percent scanning and threats associated with terrorism there are some similarities with the simulation framework described here with regards to methodology and the modeling of detection processes. Further Bakshi et al. (2011) conclude that a "one-size-fits-all" approach does not work for all terminals. This underlines the need to develop a flexible simulation framework, as it is the case in this paper, which can be applied to the workflow at different border crossings.

Other scholars including e.g. Gaukler et al. (2012) and McLay and Dreiding (2012) apply operations research methods to the problem of detecting nuclear material in cargo containers in port. Gaukler et al. (2012) compare the existing inspection system for nuclear materials detection in containers with two alternatives which make use of radiography information to decide on the routing of containers through the detection architecture. They find systems which utilize additional information gained through X-ray to outperform the current approach for a wide range of scenarios. The work by McLay and Dreiding (2012) deals with identifying optimal strategies for escalating containers to a secondary scanning stage given multiple devices in the first stage such that the overall detection probability is maximized within certain budget constraints. In contrast to the research on linear programming in the context of container scanning this paper focusses on event simulation to analyze security issues and cargo screening problems.

Research comparable to this paper regarding the methodology applied – discrete event simulation - has been done by Siebers et al (2009). They describe a first approach to develop a cargo screening process simulator which enables customs to identify optimal technology set ups given certain commodity-threat combinations in order to maximize the likelihood to detect illicit cargo. In subsequent work the outlined concept is applied to a case study for cargo screening facilities in the Port of Calais (Siebers et al, 2011; Sherman et al., 2012). For a very specific threat - clandestines trying to cross the UK border hidden in lorries – they compare different methods for conducting a cost-benefit analysis one of which is discrete event simulation.

4 Simulation-framework

EU border crossing sites are characterized by unique conditions and face individual challenges. Logistical settings such as available space and the specific flow of containers at each border crossing is different. Further, illicit trade of goods is a dynamic field with constantly changing routes and adjustments in modality, quantities smuggled per load as well as concealment methods. Accordingly, customs deal with different types of threat scenarios in terms of a combination of legitimate cargo and illicit goods. Against this background, customs have to identify a detection architecture which best fulfills their specific needs and requirements while taking into consideration conflicting objectives (balancing security and the impairment of legitimate cargo flow) within given constraints regarding budget, capacity and available resources.

Considering the above, a systemic European solution how to make best use of innovative NII technologies to prevent illicit trade and smuggling must be adaptable to different types of borders and be able to take into account the local risk profile representing the flow of illicit goods and respective threats in one location. A one-size-fits-all solution or methodology cannot cope with this challenge.

The simulation-framework for illicit-goods detection in large volume freight presented in this section is supposed to be a flexible tool which can help customs configure the detection architecture and workflow concept for a specific border crossing point. Discrete event simulation provides a practical way to compare different technology set ups and combinations and analyze their respective detection performance. Further the approach makes it possible to determine how innovative NII technologies can be integrated best into the overall flow of containers through the detection architecture and evaluate important performance measures such as total lead times, waiting times experienced in the inspection process or NII system utilization. Thus, the simulation framework supports identifying economically and practically effective technology combinations and scanning sequences for a given threat profile at a certain border crossing and within specific local logistics and workflow requirements.

Any model is a simplified representation of a real world system. Accordingly certain assumptions are necessary to transfer the actual system into a simulation environment. In order to represent a detection architecture within the proposed simulation framework the following three elements are defined and transferred into the simulation model:

— Individual detection performance values for all detection processes
— Decision making logic linking individual detection processes
— Logistical process between individual detection processes

The detection performance value represents the probability that a particular technology will correctly identify different commodity-threat combinations or produce a false alarm. Within the simulation framework detection processes are modeled as “servers” with dedicated properties. Servers are predefined modules in the simulation software, which represent a generic process step. With regards to the detection performance of individual technologies the logic of probability models as introduced in Section 2 is applied. Accordingly an expected value of the probability that an alarm is raised although no threat is present and an expected value of the probability that no alarm is raised although a threat is present is defined. If several threats or commodity-threat combinations are to be modeled at the same time, respective detection performance values for different technologies can be integrated in a detection rate matrix as proposes by Siebers et al (2009).

The decision making logic between individual detection processes within the simulation framework determines the routing of objects (containers) through the model. In the simplest case a detection process has two possible outcomes: an alarm is raised or the object is cleared. The decision making logic defines the next step within the overall detection architecture for both outcomes. A more complex decision making logic is required in case a detection process has more than two possible outcomes (e.g. a high, medium or low detection sensor reading) or in case additional information (e.g. from manifest or previous scanning process) is taken into consideration to make a decision about the routing of the object through the detection architecture.

The logistical process between individual detection steps describes the flow of containers within the model. It includes all main logistical drivers of system performance. The following parameters are defined:

— The rate at which containers arrive over time
— The time it takes for an object to move from one server to the next
— The capacity of individual servers (number of objects which can be handled simultaneously)
— The time required for a server to complete a process

Probability distributions are used to characterize process and arrival times respectively. Additionally site specific logistical constraints and characteristics such as available space and the flow of containers at a particular border crossing can be considered accordingly.

5 Case Study

This section gives results for an exemplary case study comparing a single device detection architecture with a two device system by applying the proposed simulation-framework for large volume freight introduced in the previous Section 4. Different performance measures are calculated for each scenario in order to illustrate the tradeoff between reducing the overall false clear probability or reducing the false alarm rate in case a second device is added to the detection architecture. Additionally the logistical impact is highlighted by means of lead time (total inspection time), waiting times experienced and system utilization. In case the simulation framework is applied to an actual detection architecture both can support customs management in making an informed decision with regards to performance and cost factors.

The simulation framework is implemented in the discrete event simulation software Enterprise Dynamics by the company INCONTROL. This particular software was selected due to its high flexibility regarding nonstandard processes on the one hand and the comprehensive library of modules for standard processes on the other hand. Different simulation modules, like sources, queues, servers and sinks, are used to build up the detection architecture and, where necessary, amended with specific program code to match the desired process logic and behavior. Sources are the origin of containers entering the detection process. Queues represent waiting or storage areas, if for example containers line up in front of a scanning facility, because only one container can be scanned at a time. Servers take on the role of any time consuming process, like scanning, analyzing or transportation. Sinks are the final destination of containers after completing the detection process. Based on these modules detection architectures can be created and modified quickly. Results of simulation runs are exported to Microsoft Excel for a comprehensive analysis.

5.1 Design

X-ray imaging detection technology is the central component in almost all customs detection architectures (CDTEG, 2014). In the case study it is represented as “Scanning A”. Scenario A represents the single device detection architecture where only Scanning A is used. For the two device detection architecture in Scenario B and Scenario C, X-ray is complemented with another detection device “Scanning B”. Due to logistical reasons (lower process time) Scanning B takes place previous to Scanning A. Naturally other arrangements are possible. The corresponding decision making logic between individual detection processes for all three detection architectures is shown in figure 3.

All three scenarios are analyzed for a hypothetical border crossing point with a simulation run having a time horizon of five years. The process of screening is not modeled explicitly. It is assumed that containers entering the system had previously been selected as high-risk and thus forwarded to further scanning. Only one type of threat is considered. Scanning results of each detection process are based on the true classification (threat/no threat) of the container. Alarm respectively clear probabilities are calculated as introduced in Section 2. Individual device responses are assumed to be independent.

The actual share of containers arriving in a given port that contain a threat is highly sensitive information. The same applies to detection performance values of individual NII technologies. Conditional probabilities used in this calculation are partially estimated based on discussions with customs organizations. Because of the sensitive nature of some of the data used in the simulation the values itself are not reported. For a validation results and behavior of the simulated system were compared with available customs data. A further refinement of the model is foreseen once customs feedback on simulation results becomes available.

It is not the intention of the case study to calculate the exact detection performance. Rather results of the case study are supposed to illustrate the general behavior of single compared to multiple device detection architectures. For this purpose Scanning A is assumed to produce a higher rate of false alarms compared to Scanning B. Scanning B on the other hand is assumed to produce a higher rate of false clears compared to Scanning A. Physical inspection is considered to be 100 percent successful in detecting illicit goods.

About 250 000 container enter the detection architecture during each simulation run. The arrival time is characterized by a negative-exponential probability distri-

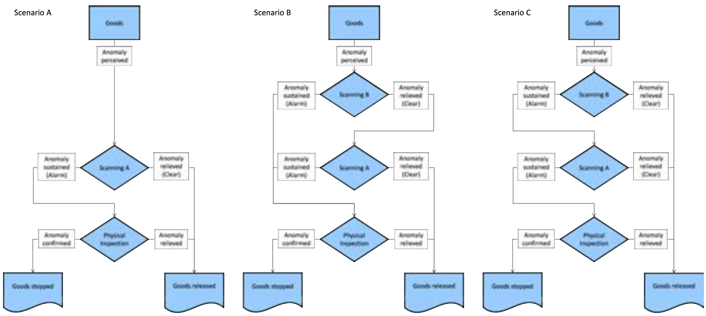

Figure 3: Detection architectures considered in case study

bution. During nighttime the arrival rate is lower by the factor of ten. Process-time distributions of individual servers in the model are approximated based on system insider judgements about average, maximum and minimum process time and as well as observations made at border crossing points. The capacity of individual servers (number of objects which can be handled simultaneously) assigned to Scanning A and physical inspection is defined in a way that waiting times during the day are the exception. For Scenario B and Scenario C the capacity assigned to Scanning A and physical inspection is not changed. Scanning B capacity, again, is defined in a way that waiting times at associated servers are the exception. Several different performance measures are calculated for each scenario:

- Number of false clears
- Share of containers sent to physical inspection
- Time containers spend in the detection architecture
- Utilization rate of physical inspection resources

5.2 Results

Table 2 shows important results of the simulation experiments for the three considered scenarios. The results are given as relative values compared to Scenario A. Accordingly, Scenario A has a value of 1 for all three key indicators.

Table 2: Results of case study

	Scenario A	Scenario B	Scenario C
Number of false clears[1]	1.00	0.62	12.20
Number of false alarms[1]	1.00	1.47	0.02
Physical inspections[1]	1.00	1.39	0.09

1 - relative to Scenario A

The results underline the previously described effect that adding a second device to the detection architecture either reduces the overall false clear probability at the cost of a higher false alarm rate or vice versa. In Scenario B, where any device alarm results in a physical inspection, the number of false clears is reduced by 38 percent on the one hand, but on the other hand the number of false alarms increases by 47 percent. Further the number of physical inspections increases as well compared to Scenario A (plus 39 percent).

The reverse effect can be observed for Scenario C where any device clear results in goods being released. The number of false alarms is reduced significantly compared to Scenario A and the demand for physical inspections declines in the same order of magnitude. However, at the same time the number of false clears increases by a factor of 12 compared to the level calculated for Scenario A.

Accordingly, adding a second device to the detection architecture is associated with a benefit in terms of reduced false clears or reduced false alarms. However, it always comes with the price of increasing the other figure respectively.

The lead time of containers passing through the system for all considered scenarios is illustrated in figure 4. The boxplot shows the distribution of lead times per container. The lower whisker indicates the 2.5 percent quantile, the upper whiskers marks the 97.5 percent quantile. Values given in the figure represent the time a freight forwarder can expect the overall inspection process to take, once the container has arrived at the location where inspections take place. Adding a second scanning device to the detection architecture increases the median lead time in Scenario B (53 min) compared to Scenario A (31 min) because a larger share of containers undergoes physical inspection. On the other hand median lead times in Scenario C (28 min) are less than in Scenario A since Scanning B has

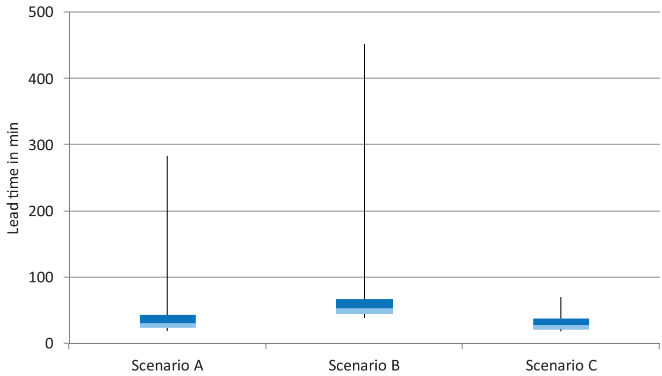

Figure 4: Lead time for all containers

a shorter process time than Scanning A and a more containers are released after the first scanning process.

The distribution of lead times shows a positive skew in all three scenarios. The reason for particular long lead times is the physical inspection process. The dispersion of lead times is highest in Scenario B where a large share of containers undergoes physical inspection and, in addition, containers experience waiting times where the physical inspection capacity is fully utilized. In contrast, Scenario C is characterized by smaller deviations in lead time compared to Scenario A and Scenario B.

Subsequently lead times for containers which did respectively did not go through physical inspection are discussed in detail.

Figure 5 contains a boxplot only for those containers which were subject to physical inspection. The median lead time for these containers is 275 min in Scenario A, 334 min in Scenario B and 288 min in Scenario C. The difference between Scenario A and Scenario C is approximately the time required for Scanning B. In Scenario B the median of 334 min is already affected by the increased number of cases that experience waiting times due to full utilization of physical inspection capacity. Of course this effect could be reduced by an extension of the physical inspection

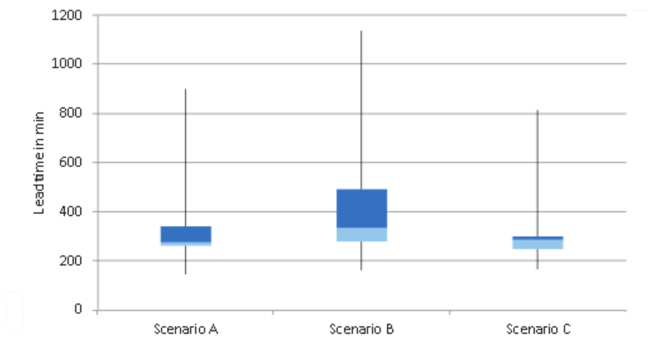

Figure 5: Lead time for containers that went through physical inspection

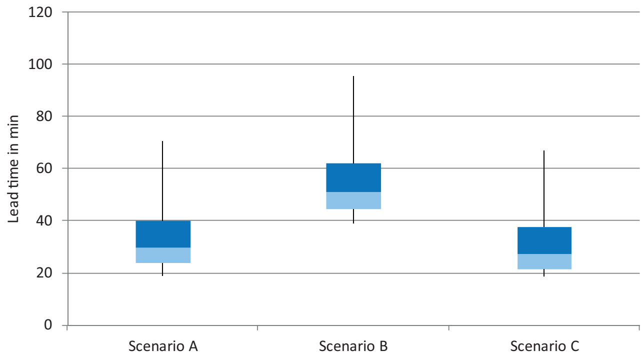

Figure 6: Lead time for containers that did not go through physical inspection

facilities. The high values of the 97.5 quantile in Scenario A and Scenario B (900 min and 1140 min) are a combination of waiting times for physical inspection and a long physical inspection process itself which occurs for some containers. The latter effect also explains the position of the 97.5 percent quantile in Scenario C. It is lower than in the other scenarios though since fewer containers undergo physical inspection in Scenario C and accordingly it is less likely for a container to experience waiting time prior to physical inspection.

If only the lead time of containers that did not go through physical inspections are analyzed, the results look somewhat different (see figure 6). The median lead time per container is shorter with 30 min in Scenario A, 51 min in Scenario B and 28 min in Scenario C. The difference of approximately 20 min between Scenario A and Scenario B corresponds to the process time of Scanning B plus waiting time experienced by some of the containers. Lead times on the upper bound (97.5 percent quantile) in Scenario A and Scenario C are around 70 min and 95 min.

The different detection system architectures designs also have a large effect on the utilization of individual system components and in particular on the utilization of the physical inspection process. In the base case, Scenario A, the median of

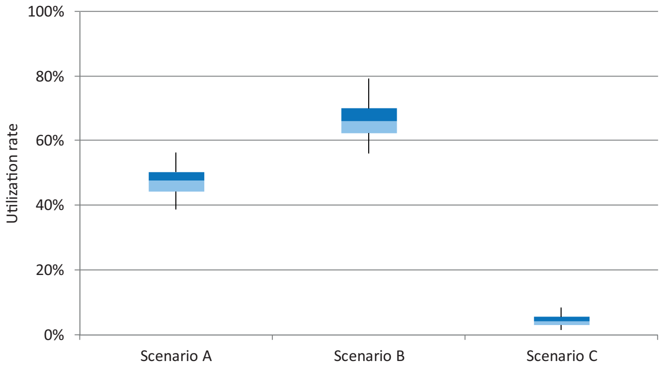

Figure 7: Average utilization rate of physical inspection per month

the average utilization rate per month at the physical inspection facilities is 48 percent (see figure 7). This is relatively high considering that the majority of the containers arrive during daytime and only few during night. As discussed before, the facilities for physical inspection are in little use in Scenario C where the median utilization rate is 4 percent. In Scenario B, on the other hand, the overall number of physical inspections is high. Consequently the utilization rate of the physical inspection facilities goes up and containers frequently experience waiting times. This increases costs either in terms of higher generalized transport costs or due to an extension of the physical inspection capacity to reduce waiting times. On the other hand the number of false negatives is lower in Scenario B which represents a comparative benefit. Fewer shipments are falsely cleared, thus the cost which society has to absorb in terms of negative socio-economic effects associated with illicit trade is reduced. This underlines that comparing the cost to benefit ratio of different detection architectures can be a suitable basis for decisions by customs management and policy makers.

6 Conclusion

Overall the role of maritime container trade in the transportation of illegal goods across borders is characterized by a comparatively low number of seizures but generally larger consignments of illicit goods than in other transport modes (see e.g. WCO, 2016). At the same time scholars have highlighted the potentially devastating impact that terrorist attacks could have in the maritime context overall and associated with maritime container transport in particular (see e.g. Greenberg et al., 2006; Schneider, 2011). Both emphasizes the importance of constantly improving detection architectures and thus effectively and efficiently preventing illicit trade while facilitating free flow of legitimate cargo across EU-borders.

This paper introduces a simulation-framework for illicit-goods detection in large volume freight. The framework represents an effective and flexible tool for customs to analyze different NII technology set ups - detection architectures – against their requirements without interrupting activities at a border crossing point. At the same time the applied method, discrete event simulation, provides the means to take logistical settings such as available space and the specific flow of containers into account and analyze important performance indicators such as average inspection times but also its variation e.g. expressed by inspection times in the upper quartile.

An illustrative case study demonstrated how a detection architecture can be analyzed with the simulation-framework. It compared a single device detection architecture with two variants of a two device architecture regarding the overall detection performance. Results show that by adding a second device to the detection architecture it is not possible to increase the relative chance to detect a threat (lower probability of false clears) and reduce the share of containers which unnecessarily undergo physical inspection (lower probability of false alarms) at the same time. It was demonstrated that a multi device detection architecture where any device alarm results in physical inspection will reduce the probability of false clears while a detection architecture where any device clear results in goods being released will reduce the probability of false alarms compared to the single device architecture.

Furthermore the impact of adding a second device on lead times and capacity utilization was shown in the case study. A multi device detection architecture does not inevitably mean that lead times increase. Whether they do or not depends on the logical structure of the detection architecture. The same applies for the utilization rate of e.g. the physical inspection resources which can either increase or decrease compared to the single device architecture depending on the logic linking individual detection processes.

Findings described here are only a first step towards building a comprehensive simulation-framework for illicit-goods detection in large volume freight. There are several possible extensions to this work. A first extension is to implement different types of threats and specific capabilities of technologies to detect these threats in the model in order to analyze the full range of illicit trade customs deal with. A second extension is to consider information gained in one scanning process in the decision how the container is routed through subsequent scanning devices. This implicates a more complex decision making logic linking individual detection processes which might also take into account the current utilization of NII scanning equipment and physical inspection stations to reduce waiting times during peaks. A third extension is to quantify direct and indirect cost associated with different detection outcomes (true alarm, false alarm, false clear, true clear), the detection process itself as well as increases of generalized transport cost due to potential delays. This way changes in different cost factors could be weighed against each other, adopting the concept of cost-benefit analysis, to provide a more comprehensive basis for customs management and policy makers to take informed decisions. Work is in progress to address these extensions.

Financial Disclosure

This work has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 653323. This text reflects only the author's views and the Commission is not liable for any use that may be made of the information contained therein.

References

Acxis project (2016). *ACXIS Automated Comparison of X-ray Images for cargo Scanning*.

Bakshi, N., S. E. Flynn, and N. Gans (2011). "Estimating the Operational Impact of Container Inspections at International Ports". In: *Management Science* 57.1, pp. 1–20.

C-BORD project (2017). *Effective Container Inspection at BORDer Control Points*. www.cbord-h2020.eu.

CDTEG (2014). *Detection Architecture*. Brussels.

CRIM-TRACK project (2014). *CRIM-TRACK*. www.crimtrack.eu.

Gaukler, G. M., C. Li, Y. Ding, and S. S. Chirayath (2012). “Detecting Nuclear Materials Smuggling: Performance Evaluation of Container Inspection Policies”. In: *Risk Analysis* 32.3, pp. 531–554.

Greenberg, M. D., P. Chalk, H. H. Willis, I. Khilko, and D. S. Ortiz (2006). *Maritime Terrorism: Risk and Liability*. Santa Monica, CA: RAND Corporation.

Hintsa, J. and S. Mohanty (2014). “A Literature-Based Qualitative Framework for Assessment of Socio-Economic Negative Impacts of Common Illicit Cross-border Freight Logistics Flows”. In: *Innovative Methods in Logistics and Supply Chain Management: Current Issues and Emerging Practices*. Ed. by T. Becker, W. Kersten, and C. M. Ringle. Berlin: epubli, pp. 319–340.

INTERPOL (2014). *Countering Illicit Trade in Goods: A Guide for Policy-Makers*. Lyon.

Jacobson, S. H., T. Karnani, J. E. Kobza, and L. Ritchie (2006). “A Cost-Benefit Analysis of Alternative Device Configurations for Aviation-Checked Baggage Security Screening”. In: *Risk Analysis* 26.2, pp. 297–310.

Kobza, J. E. and S. H. Jacobson (1997). “Probability models for access security system architectures”. In: *Journal of the Operational Research Society* 48.3, pp. 255–263.

Langen, P. W. d. and M. N. Nijdam (2007). “Charging Systems for Waste Reception Facilities in Ports and the Level Playing Field: A Case from North-West Europe”. In: *Coastal Management* 36.1, pp. 109–124.

Martonosi, S. E., D. S. Ortiz, and H. H. Willis (2005). “Evaluating the viability of 100 per cent container inspection at America’s ports”. In: *The Economic Impacts of Terrorist Attacks*. Ed. by H. W. Richardson, P. Gordon, and J. E. Moore II. Cheltenham: Edward Elgar Publishing, pp. 218–241.

McLay, L. A. and R. Dreiding (2012). “Multilevel, threshold-based policies for cargo container security screening systems”. In: *European Journal of Operational Research* 220.2, pp. 522–529.

Schneider, P. (2011). *Maritimer Terrorismus: Tätergruppen und Anschlagstypen 1968 – 2010. PiraT Arbeitspapier zur Maritimen Sicherheit Nr. 13.* Hamburg.

Sherman, G., P.-O. Siebers, D. Menachof, and U. Aickelin (2012). “Evaluating Different Cost-Benefit Analysis Methods for Port Security Operations”. In: *Decision Making in Service Industries: A Practical Approach*. Ed. by J. Faulin, A. A. Juan, S. E. Grasman, and M. J. Fry. Boca Raton, FL: CRC Press, pp. 279–303.

Siebers, P.-O., U. Aickelin, and G. Sherman (2009). “Development of a Cargo Screening Process Simulator: A First Approach”. In: *21st European Modeling and Simulation Symposium (EMSS 2009), Volume I*. Ed. by R. M. Aguilar, A. G. Bruzzone, and M. A. Piera.

Siebers, P.-O., G. Sherman, U. Aickelin, and D. Menachof (2011). “Comparing Decision Support Tools for Cargo Screening Processes”. In: *The 10th International Conference on Modeling and Applied Simulation (MAS 2011)*. Ed. by A. Bruzzone, C. Frydman, M. Massei, M. McGinnis, M. A. Piera, and G. Zacharewicz.

U.S. Congress (n.d.). *H.R.1: Implementing recommendations of the 9/11 commission act of 2007: Pub. L. No. 110-53, 110th Congress*.

Wilson, D. (2005). “Use of modeling and simulation to support airport security”. In: *IEEE Aerospace and Electronic Systems Magazine* 20.8, pp. 3–6.

World Customs Organization (2012). *SAFE Framework of Standards to Secure and Facilitate Global Trade*. Brussels.

World Customs Organization (2016). *Illicit Trade Report 2015*. Brussels.

World Shipping Council (2017). *Trade Statistics*.

Relational View on Collaborative Supply Chain Disruption Recoveries

Marie Brüning[1], Julia Bendul[1]

1 – Jacobs University Bremen

Due to their growing global and complex nature, supply chains are increasingly vulnerable to natural and man-made disasters that disrupt the flow of goods. Today, recovering from supply chain disruptions represents a major challenge for supply chain professionals. In research, most recovery methods suggested are based on redundancy and flexibility. In practice, a different approach gains momentum: companies recover by collaborating with their supply chain partners, especially by temporarily sharing resources. Based on the relational view theory, this paper uses multiple case studies and expert interview to develop a framework which describes the factors promoting collaborative resource sharing as well as the effect on supply chain resilience.

Keywords: Supply Chain Risk Management; Supply Chain Resilience; Supply Chain Collaboration; Shared Resources

1 Introduction

Supply chain (SC) disruptions are “unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain” (Craighead et al., 2007). In 2016, two of Volkswagen’s suppliers halted delivery of transmission and seat parts, following previous unresolved disputes between the parties. This led to stops of series production in seven German Volkswagen production sites. Additionally, several other suppliers were affected as well (Reuters, 2016). This example shows immediate consequences of SC disruptions, such as increasing costs as well as decreasing profitability and net sales. Long-term effects of disruptions are negative stock market reactions, damaged brand image and decreased customer service levels (Bello and Bovell, 2012; Craighead et al., 2007; Hendricks and Singhal, 2005).

The topic of managing SC disruptions becomes increasingly important due to three reasons. First, quantities as well as severities of natural and man-made disasters are expected to continue rising (Munich Re, 2016; SwissRe, 2016). Second, current business trends in the area of supply chain management (SCM), such as reduction of supplier base, just-in-time inventory system, outsourced manufacturing, and global sourcing, create highly interconnected global SC with fewer buffers and more risk exposure points. This increase the potential for and the impact of a SC disruption (Bello and Bovell, 2012; Craighead et al., 2007; Stecke and Kumar, 2006; Thun and Hoenig, 2011; Tukamuhabwa et al., 2015). Third, the recovery from SC disruptions is one of the main concerns of SC managers. However, it seems that companies are not well prepared for a fast recovery (Deloitte, 2013). Thus, there is a need to understand and implement risk management methods that facilitate the recovery of disruptions (Bovell, 2012).

Collaborative recovery as a reactive risk management method is rather new to the field of supply chain risk management (SCRM) and not yet holistically explained in literature. SC partners gain collaborative advantage by sharing their resources during disruption recoveries. This perspective is based on the relational view theory which states that collaborative advantage can be gained by leveraging inter-organizational resources available in the network (Dyer and Singh, 1998). In this research specifically one element of supply chain collaboration (SCC) is analysed, namely the sharing of resources. This paper aims to develop a collaborative recovery framework that encompasses promoting factors of collaborative resource sharing and its effect on supply chain resilience (SCRES). In addition, managerial implications are derived.

The paper is structured as follows. Chapter two covers a literature review of the concepts SCC and SCRES as well as the connection between both. In chapter three the methodology is outlined. In chapter four the developed framework is described in detail. Chapter five covers limitations, suggestions for further research and managerial implications.

2 Literature Review

This research project builds on the relational view as a theoretical foundation. The relational view theory, initially developed by Dyer and Singh (1998), is an extension of the resource-based view. The trend that networks of collaborating companies, instead of individual companies, compete against each other was the basis for its development. Dyer and Singh (1998) state that inter-firm linkages and inter-organizational resources may be a source of relational rents and collaborative advantage. Relational rent refers to "supernormal profit jointly generated in an exchange relationship that […] can only be created through the joint idiosyncratic contribution of the specific alliance partners" (Dyer and Singh, 1998). One of the determinants of relational rent, and thus of collaborative advantage, is complementary resource endowment. It is defined as "distinctive resources of alliance partners that collectively generate greater rents than the sum of those obtained from the individual endowments of each partner" (Dyer and Singh, 1998). Collaborative advantage refers to joint value creation and benefits gained over competitors in the marketplace through supply chain partnering (Cao and Zhang, 2013).

Within SCRM literature, there are two categories of SC disruption management methods: Preventive methods are used in advance of a disruption to reduce its likelihood. Reactive methods are used if a disruption occurred, thus during the recovery. The focus is to limit the severity of disruptions (Simchi-Levi, Schmidt and Wei, 2014; Stecke and Kumar, 2006). In SCRM literature, reactive measures receive considerably less attention than preventive measures (Tukamuhabwa et al., 2015). Furthermore, most of the existing reactive methods, such as excess inventory, multiple sourcing and rerouting of transports, focus on redundancy and flexibility (Christopher and Peck, 2004; Stecke and Kumar, 2006). These are not in line with the described current business trends as they involve high inventory and coordination costs (Chopra and Sodhi, 2014).

In this research the term SCRES is used to describe reactive methods only. SCRES is defined as the SC's ability to recover from a disruption and restore to normal operations in a timely manner more favourable than competing SC (Christopher and Peck, 2004; Ponis and Koronis, 2012; Ponomarov, 2012; Wieland and Wallenburg, 2013). This definition implies the core idea of the relational view theory by arguing that SC recover better, i.e. faster, than competing SC and can, therefore, gain a collaborative advantage.

SCC is defined by Cao et al. (2010) as a "long-term partnership process where supply chain partners with common goals work closely together to achieve mutual advantages that are greater than the firms would achieve individually". The relational view theory is also reflected in this definition. Long-term SC relationships create value that neither partner would have been able to create independently (Nyaga, Whipple and Lynch, 2010). Companies seek to build collaborative relationships because in this way they can access complementary resources and improve collaborative advantage (Cao and Zhang, 2013; Dyer and Singh, 1998; Mohr and Spekman, 1994).

According to Cao et al. (2010), resource sharing is an element of SCC and defined as "the process of leveraging capabilities and assets and investing in capabilities and assets with supply chain partners". They do not discuss resource sharing in the context of a time-limited event, such as a SC disruption recovery. Rather they discuss resources which are continuously shared. Resources are a key component of the relational view theory (Dyer and Singh, 1998). Lavie (2006) argues that companies can obtain value from resources which are not controlled or fully owned by their internal organization.

The topic of collaborative recovery can be located at the intersection of SCC and SCRES because it is a reactive disruption management method which is based on the effort of multiple companies within a SC. There are a few similar concepts described in literature. The research of Bello and Bovell (2012) as well as Wieland and Wallenburg (2013) focus on relational factors relevant to gain SCRES in collaborative relations. According to Bello and Bovell (2012), a gap exists in disruption recovery literature regarding the attention paid to relational resources that enable collaboration. Bovell (2012) highlight the value of collaborative resource sharing with respect to SCRES. Bode et al. (2011) presents the reactive methods 'bridging' which focuses on collaborative actions, like establishing relationships with influential individuals in partner companies. Furthermore, they find that the levels of trust and dependency are decisive in choosing a reactive method. Whitney et al. (2014) discuss and analyze the method 'temporary sourcing diversification' which captures the temporary nature of the recovery process. Overall, there is a research gap with regard to reactive risk management methods that focus on relational resources as well as on resources temporarily shared during disruption recoveries. This research attempts to give some insights into this area.

3 Methodology

Developing a theoretical framework is understood as an iterative process. Kubicek (1976) describes the attempt to derive practical knowledge by interacting with practitioners, theoretical processing and reflection of the obtained knowledge in order to derive new questions for practitioners as iterative heuristic. The theoretical framework was continually modified with experience and information from a comprehensive literature review, case studies and expert interviews (for an overview of the executed interviews and case studies see appendix).

Six case studies were conducted based on secondary data (Brüning, Hartono and Bendul, 2014). The method is appropriate for this research because case studies are valuable for rather unexplored topics (Eisenhardt, 1989; Voss, Tsikriktsis and Frohlich, 2002). To ensure validity and reliability, established structured procedures were employed, such as case study protocols and case selection criteria. The case subjects had to have experienced a disruption that had consequences for multiple SC actors and there had to be some kind of SCC during the recovery. For the data collection different types of archival sources were consulted, such as company reports, reports from recognized organizations, newspaper articles, and academic literature.

Eight semi-structured expert interviews were executed. The dialog between interviewer and interviewee reflects the iterative framework development process (Kubicek, 1976). The interviewed experts are practitioners working in manufacturing industry, insurance or consulting, who are either dealing with or are/were affected by SC disruptions. An interview guideline was developed (Flick, 2006) based on the findings from literature review and case studies. The questions mainly focus on the company's experiences with collaboration during disruption recoveries and the general collaboration in their SC. There was sufficient time between the interviews to refine the guideline in between sessions. Eight expert interviews approximately 30 minutes were carried out over a time period of six months. The interviews were held in person or via telephone, depending on the preference of the interviewee. Seven of the interviewees gave permission for the recording of the interview via digital voice recorder. Each interview was summarized in a protocol. The interviewees reviewed their protocols which, in turn, were improved based on their feedback (Voss et al., 2002).

4 Framework Development

Based on the methods described, a framework was developed that encompasses relevant factors to describe the risk management method collaborative recovery (figure 1).

4.1 Collaborative Resource Sharing

Starting point for the framework development is the central construct 'collaborative resource sharing'. It describes the actual temporary sharing of resources during disruption recoveries. The interviews and case studies were analysed with regard to three topics, namely the types of resources shared, the resources' abilities, and the actors sharing the resources (Brüning, Hartono and Bendul, 2015).

First, human resources (HR) and production resources (PR) are the two identified categories of resources shared during collaborative recoveries. HR include employees, managers and engineers as well as their know-how and skills. In all analysed cases HR were shared. For instance, to support Aisin's recovery, Toyota

Figure 1: Theoretical Framework

sent around 400 employees from various departments (Nishiguchi and Beaudet, 1998). In the automotive and aerospace industry, original equipment manufacturers (OEM) have task forces which consist of skilled engineers and/or managers (interviews AeroOEM1, AutoOEM1, AutoOEM2). They can be sent on site in case of a SC disruption. PR cover equipment, tools, facilities, machine capacities and warehouse capacities as well as information and know-how, for instance about production processes. There are examples of companies in the food industry that used machine and warehousing capacities of competitors during SC disruption recoveries (interview Funk RMCE).

Second, adaptability, mobility and availability of capacity are the identified abilities which enable resources to be shared during SC disruption recoveries. HR have to be able to adapt to new tasks. For instance, in the case of Aisin, employees from their suppliers and customers could quickly adapt to produce the needed parts (Nishiguchi and Beaudet, 1998). Adaptability of PR refers to the ability of changing tools, machines or warehouses according to new requirements. The ability 'mobility' refers to HR's and PR's ability to move. In the case of Renesas, more than 2,500 engineers from other companies were mobilized and came to the disrupted plant. In order to exchange information, recovery activity team leaders had daily meetings to discuss the progress of the recovery (Renesas, 2011). Resources need to have capacity available (Whitney et al., 2014). With regard to HR, employees need to have capacity to take over new tasks. This may be accomplished with additional shifts or with established task forces (interviews AeroOEM1, AutoOEM1, AutoOEM2, AutoOEM3). For PR, it is required that machines or warehouses have capacity available to take over production processes on short notice (interviews AeroOEM1, Funk RMCE).

Third, the identified involved actors cover intra-organizational, horizontal as well as vertical collaboration. Intra-organizational collaboration exists, for instance, between different subsidiaries of one company (Barratt, 2004). During Nissan's recovery, hundreds of employees from other Nissan plants worldwide were involved in the repair work at the damaged facilities (Nissan, 2012). Vertical collaboration with customers and suppliers (Barratt, 2004; Simatupang and Sridharan, 2002) is most frequently used (interviews AeroOEM1, AutoOEM3, Controllit OHB, Funk RMCE). Customers are the actors that are involved in all analyzed cases. Second tier customers and second tier suppliers may also be involved in collaborative recoveries, like in Aisin's recovery (Whitney et al., 2014). These indirect relationships are activated only for the time of the recovery (interviews AutoOEM1, Funk RMCE). Horizontal collaboration refers to collaboration with competitors or other unrelated organizations (Barratt, 2004; Simatupang and Sridharan, 2002). Collaboration with competitors during recoveries happens rarely (interviews AutoOEM1, AutoOEM2) due to antitrust and privacy issues (interview OHB). Also governmental organizations may share their resources. For instance, soldiers and equipment from the Thai Army and Thai Navy supported the recovery of Western Digital (Wai and Wongsurawat, 2013). The relevant roles of logistics service providers and insurance companies were highlighted by some interviewed experts (interviews AutoOEM1, Lampe and Schwartze). They seem to be valuable due to their neutral supervising position within the network.

4.2 Promoting Factors

Three relational resources that promote collaborative recoveries are identified. A collaborative culture among SC partners seems to be beneficial for collaborative recoveries and is characterized by the relational resources 'trust' and 'commitment'. Literature in the field of SCC frequently emphasizes a close connection between the two concepts (Kwon and Suh, 2005; Morgan and Hunt, 1994; Nyaga et al., 2010; Ryu, So and Koo, 2009). Both will be discussed in the following paragraphs. 'Dependency' seems to be the main motivation for companies to collaborate during SC disruption recoveries and will be discussed afterwards.

4.2.1 Trust and Commitment

Trust is defined by Rousseau et al. (1998) as "the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another". The concept of trust is composed of two main dimensions (Bode et al., 2011; Cao and Zhang, 2013; Kumar, Scheer and Steenkamp, 1995; Nyaga et al., 2010; Sheu, Yen and Chae, 2006). According to Doney and Cannon (1997), credibility is the "expectancy that the partner's word or written statement can be relied on" and benevolence is the "extent to which one partner is genuinely interested in the other partner's welfare and motivated to seek joint gain".

Several studies found strong associations between SC partners' trust and relationship success. For instance, Sheu et al. (2006) point out the criticality of trust for supplier-retailer collaboration. According to Mohr and Spekman (1994), trust is a primary characteristic of partnership success. Relationships with a high level of trust are willing to take risks between partners (Kwon and Suh, 2005; Li et al., 2015). According to McEvily et al. (2003), trust can be a mobilizer that motivates companies to contribute and combine their resources in joint activities to achieve their goals and to resolve problems.

Morgan and Hunt (1994) define commitment as “an exchange partner believing that an ongoing relationship with another is so important as to warrant maximum efforts at maintaining it; that is, the committed party believes the relationship is worth working on to ensure that it endures indefinitely”. Commitment generally encompass three dimensions, namely affective commitment (“the desire to continue a relationship because of positive affect toward the partner”), expectation of continuity (“the firm’s perceptions of both its own and its partner’s intent to remain in the relationship, which, thereby, reflect the relationship’s stability”), and willingness to invest in the relationship (“the intention to become more deeply involved in the relationship through investments of capital and effort”) (Kumar et al., 1995).

A large amount of studies stress the relevance of commitment in collaborative relationships. The results of Mohr and Spekman’s study (1994) indicate that one primary characteristics of partnership success is commitment. This is because commitment creates a context in which parties can achieve their long-term individual and joint goals without being concerned about opportunistic behaviour. Ryu et al. (2009) argue that commitment foster the integration of partnerships among SC partners. The studies of Nyaga et al. (2010) show that trust and commitment leads to improved satisfaction and performance in collaborative relationships between SC partners.

The analysed cases show a high degree of trust and commitment between partners that collaborated during SC disruption recoveries. For example, Aisin was one of the most trusted of Toyota’s suppliers and main Japanese supplier of P-valves, the critical part of which the SC was disrupted (Nishiguchi and Beaudet, 1998). During Western Digital’s recovery, the customers expressed their trust and commitment in agreeing upon special provisions that deviate from normal contractual agreements (Wai and Wongsurawat, 2013). Many interviewees confirmed that high levels of trust and commitment lead to higher willingness to collaborate during disruption recoveries (interviews Lampe and Schwartze, OHB). For example, OHB treat their suppliers as partners that share risk and solve problems jointly as they work towards a common goal (interview OHB). Based on the described literature that emphasizes the key role of trust and commitment in collaborative interorganizational relationships as well as the results of the case study analysis and interviews, the following propositions are derived:

Proposition 1: A high level of trust between SC partners leads to a high level of collaborative resource sharing during disruption recoveries.

Proposition 2: A high level of commitment between SC partners leads to a high level of collaborative resource sharing during disruption recoveries.

4.2.2 Dependency

"Dependence exists when one party does not entirely control all of the conditions necessary for achievement of an action or a desired outcome" (Handfield and Bechtel, 2002; Monczka et al., 1998). In literature, several authors suggest a positive effect of dependency on SCC. Sheu et al. (2006) show that interdependence between parties is one essential factor for interorganizational relationships because it motivates to share key information and participate in joint efforts. According to Monczka et al. (1998), interdependence as an attribute of supplier alliances was found to be significantly related to partnership success. As stated by Hudnurkar et al. (2014), the structure of dependency relationships is highly relevant for successful collaborations as it has essential implications for joint efforts, including problem solving.

The dependency on a partner is often connected to the relevance of a product which is characterized by high levels of customization, supply scarcity, technical complexity and/or novelty of technology (De Leeuw and Francoo, 2009; Whitney et al., 2014). According to De Leeuw and Fransoo (2009), the more the poducts are relevant, the more close SCC is expected. Nokia depends on Philips' production because only they can supply specific components needed for producing a type of cell phone chip (Sheffi, 2005). Similarly, Renesas' microcontrollers are custom-made which makes switching to another supplier difficult (Pollack, 2011). However, the interviews and case studies show that also other forms of dependency exist. The disruption of one supplier can lead to strategic problems for other suppliers. In the case of Aisin, hundreds of suppliers, local electricity, gas and transportation companies had to wait for Aisin to reopen the plant in order to resume deliveries (Nishiguchi and Beaudet, 1998). In addition, the current SCM business trends, especially single sourcing, leads to a high level of dependency. The importance of dependency with regard to collaborative recovery was stressed by all interviewed experts. The interviewees of Lampe and Schwartze said that during disruption recoveries, they and their partners are "all in the same boat". Dependency seems to be the main trigger that motivates actors to get involved in collaborative recoveries, which is reflected in the following proposition:

Proposition 3: A high level of dependency between SC partners leads to a high level of collaborative resource sharing during disruption recoveries.

4.3 Supply Chain Resilience

Following the relational view line of argumentation, SCRES is achieved if a SC recovers better than its competing SC, thus if a collaborative advantage is derived. The success of a recovery is derived from its so-called time to recover (Simchi-Levi et al., 2014). This is the time period between the occurrence of the disruption and the complete restoring of the SC. Several authors stress the competitive positioning role of resilience. For example, based on an extensive literature review, Tukamuhabwa et al. (2015) conclude that companies that respond to a disruption better than its competitors can improve their market position. Rice and Caniato (2003) state that in case of disruptions, companies can compete on their resilience capabilities.

In the analysed cases, companies' time to recover was shorter compared to their competitors. Unfortunately, the cases do not always provide sufficient information about the time to recover of competing SC or companies. Instead, the expected and the real time to recover were analysed. For instance, Western Digital could successfully recover within two months. In comparison, four months after the flood that caused the disruption, only about half of the 90 affected factories in the area resumed production (Wai and Wongsurawat, 2013). The restart of Renesas' limited production was three months faster than initially anticipated by it's engineers (Olcott and Oliver, 2014; Renesas, 2011). With regard to Riken's recovery, multiple sources state that the support of its customers enabled the company to restart production much quicker than it would have without their help (Global Risk Miyamoto, 2007; Whitney et al., 2014).

As outlined by existing research and supported by the relational view theory, there is a positive relation between the concepts SCC and SCRES (Bello and Bovell, 2012; Bovell, 2012; Brüning and Bendul, 2015; Wieland and Wallenburg, 2013). For example, Christopher and Peck (2004) state that "building resilience to SC risks requires a high degree of collaboration". Based on the analyses and literature results, the following proposition can be derived:

Proposition 4: A high level of collaborative resource sharing during disruption recoveries leads to a high level of supply chain resilience.

5 Conclusion

Several companies applied the sharing of resources during disruption recoveries. However, the method of collaborative recovery was not yet holistically explained in literature. Collaborative recovery is based on the idea of the relational view theory and which states that collaborative advantage can be derived from interorganizational resources (Dyer and Singh, 1998). It is suggested that by collaborating during SC disruption recoveries, a SC can be more resilient than their competing SC. A framework to describe the promoting factors for collaborative resource sharing and its effect on SCRES was developed. Based on a literature review, case studies and expert interviews, three promoting factors were defined, namely trust, commitment and dependency. The developed propositions indicate that collaborative SC recovery has the potential to be a promising reactive risk management method.

Based on the results presented in this paper, some managerial implications can be derived. First, adaptability, mobility and availability of capacity are the identified abilities which enable resources to be shared during SC disruption recoveries. SC managers can prepare for fast recoveries by taking care that large amounts of resources (HR and PR) have these abilities. For example, interorganizational training can improve the adaptability and mobility of HR. Second, collaboration took place between different SC actors. When planning for collaborative recovery actions, SC managers may consider also collaborating with their indirect partners, for instance second-tier suppliers. In addition, companies can take advantage of logistics service providers or insurance companies and their neutral coordinating roles in SC. Third, commitment and trust were identified as the relational resources that promote collaborative recoveries. Thus, investing in strong, long-term partnerships seems to pay off during SC disruption recoveries.

The methods employed in this research have several limitations. The amount of cases and interviews conducted was limited. In addition, the cases were based solely on secondary data. Further research could aim at triangulating the information gathered. In general, case studies have limitations regarding the attainable level of generalizability (Eisenhardt, 1989).

This paper is part of a larger research project. The next steps are the operationalization of the identified constructs, the execution of a large-scale survey, and the statistical analysis of the data gathered to test the developed propositions.

Appendix: Overview of Interviews

Table 1: Overview of Interviews

Name of Interviewee	Position	Company	Industry	Date/ Type of Interview
Anonymous	Manager Production Logistics	AutoOEM 1	Automotive	04.06.2015/ face-to-face
Anonymous	Quality Sales	AutoOEM 2	Automotive	30.07.2015/ phone
Anonymous	Manager Logistics Planning	AutoOEM 3	Automotive	06.08.2015/ phone
Anonymous	Senior Manager, Procurement	AeroOEM 1	Aerospace	07.05.2015/ face-to-face
Mr. Heinrich	Director Procurement	OHB	Aerospace	18.02.2015/ face-to-face
Mr. Löffler	Managing Director	Funk RMCE	Insurance	02.06.2015/ phone
Mr. Viethen; Mr. Bening	Management Assistant	Lampe and Schwartze	Insurance	18.02.2015/ face-to-face
Mr. Rosenberg	Managing Director	Controllit AG	Consulting	29.05.2015/ phone

Appendix: Overview of Case Studie

Table 2: Overview of Case Studies

Company description	Disruption description	Recovery description SC actors (resources shared during SC disruption recoveries)
Case: Western Digital Leading electronics company; headquarter in the US; several subsidiaries in Asia	October 2011: heavy flooding in Bang Pa-In Industrial Estate, Thailand; precision equipment and supplies of material were destroyed (Wai and Wongsurawat, 2013); affected customers worldwide, as the price of external hard drives increased at least by 10% (Fuller, 2011)	– Customers (monetary resources (MR)) – Navy, army (human resources (HR), production resources (PR)) – Intra-organizational actors (employees of Western Digitial's national and international plants) (HR)
Case: Renesas Leading electronics and automotive company, world market, share of 44% (Olcott and Oliver, 2014); headquarter in Japan	March 2011: the Great East Japan Earthquake severely damaged Renesas', Naka manufacturing plant; cleanrooms were destroyed; just-in-time, production resulted in production shortages at major automotive,customers (Pollack, 2011)	– Customers (HR, PR) – Competitors (MR) – Governmental agencies (MR) – Intra-organizational actors (HR)
Case: Nissan One of Japan's largest automotive manufacturers	March 2011: the Great East Japan Earthquake hit two assembly plants; loss of production capacity of about 270,000 cars; about 50 suppliers of Nissan were directly affected by the disaster as well (Greenway, 2014)	– Customers/competitors (HR) – Suppliers (HR) – Competitors (HR) – Intra-organizational actors (HR, PR)

Continued on next page

Table 2: Overview of Case Studies (continued)

Company description	Disruption description	Recovery description SC actors (resources shared during SC disruption recoveries)
Case: Riken Japan's largest supplier of piston rings in the automotive industry (50% market share) (Whitney et al., 2014)	July 2007: Niigata Chuetsu off-shore earthquake affected one main plant and nine satellite companies (Whitney et al., 2014); operations at main plant were suspended for two weeks (Global Risk Miyamoto, 2007; Whitney et al., 2014); several automobile manufacturers (e.g. Toyota and Mitsubishi) interrupted their operations (Global Risk Miyamoto, 2007)	– Customers (automotive manufacturers, equipment manufacturers) (HR, PR) – Intra-organizational actors (HR)
Case: Philips Worldwide operating electronics company; headquarter in the Netherlands	March 2000: plant in Albuquerque, New Mexico, caught a fire because of lightning; cleanrooms were ruined and millions of chips were contaminated by smoke and water (Mukherjee, 2008)	– Customer (Nokia) (HR) – Nokia's suppliers (PR) – Intra-organizational actors (PR)
Case: Aisin Supplies mostly automotive parts, headquarter in Aichi, Japan	February 1997: fire in the factory in Aichi destroyed specialized equipment; it's customer Toyota announced a shut-down of its production lines on the following day (Nishiguchi and Beaudet, 1998; Whitney et al., 2014)	– Customers (HR, PR) – Suppliers (HR, PR) – Toyota's suppliers (HR, PR)

References

Barratt, M. (2004). "Understanding the meaning of collaboration in the supply chain". In: *Supply Chain Management: An International Journal* 1.9, pp. 30–42.

Bello, D. and L. Bovell (2012). “Collaboration analysis: joint resolution of problems in global supply networks”. In: *Information Knowledge Systems Management* 1/2.11, pp. 77–99.

Bode, C., S. M. Wagner, K. J. Petersen, and L. M. Ellram (2011). “Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives”. In: *Academy of Management Journal* 4.54, pp. 833–856.

Bovell, L. J. (2012). “Joint resolution of supply chain risks: the role of risk characteristics and problem solving approach”. In: *Department of Marketing, Georgia State University*.

Brüning, M. and J. Bendul (2015). “Self-healing supply networks: Collaborative Recovery from Supply Network Disruptions by Sharing Network Resources”. In: *Proceedings of 24th International Purchasing and Supply Education and Research Association*.

Brüning, M., N. T. Hartono, and J. C. Bendul (2014). “Collaborative Recovery from Supply Network Disruption: A Multiple Case Study”. In: *Proceedings of the 12th International Logistics and Supply Chain Congress*.

Brüning, M., N. Hartono, and J. C. Bendul (2015). “Collaborative recovery from supply chain disruptions: characteristics and enablers”. In: *Research in Logistics and Production* 3.5, pp. 225–237.

Cao, M. and Q. Zhang (2013). *Supply chain collaboration*. Hamburg: Springer.

Christopher, M. and H. Peck (2004). “Building the resilient supply chain”. In: *International Journal of Logistics Management* 2.15, pp. 1–14.

Craighead, C. W., J. Blackhurst, M. J. Rungtusanatham, and R. B. Handfield (2007). “The severity of supply chain disruptions: design characteristics and mitigation capabilities”. In: *Decision Sciences* 1.38, pp. 131–156.

Craighead, C. W., J. Blackhurst, M. J. Rungtusanatham, and R. B. Handfield (2013). “Supply chain resilience: a risk intelligent approach to managing global supply chains”. In:

De Leeuw, S. and J. Fransoo (2009). “Drivers of close supply chain collaboration: one size fits all?” In: *International Journal of Operations and Production Management* 7.29, pp. 720–739.

Doney, P. M. and J. P. Cannon (1997). “An examination of the nature of trust in buyer-seller relationships”. In: *Journal of Marketing* 2.61, pp. 35–51.

Dyer, J. H. and H. Singh (1998). “The relational view: cooperative strategy and sources of interorganizational competitive advantage”. In: *Academy of Management Review* 4.23, pp. 660–679.

Eisenhardt, K. M. (1989). “Building theories from case study research”. In: *Academy of Management Review* 4.14, pp. 532–550.

Flick, U. (2006). *An introduction to qualitative research*. London: Sage Publications.

Fuller, T. (2011). “Thailand Flooding Cripples Hard-Drive Suppliers”. In: *NYTimes.com*.

Ghadge, A., S. Dani, and R. Kalawsky (2012). “Supply chain risk management: present and future scope”. In: *The International Journal of Logistics Management* 3.23, pp. 131–339.

Greenway, T. (2014). “How safe is your Supply Chain?” In: *Delivered DHL*.

Handfield, R. B. and C. Bechtel (2002). “The role of trust and relationship structure in improving supply chain responsiveness”. In: *Industrial marketing management* 4.31, pp. 367–382.

Hendricks, K. and V. Singhal (2005). “An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm”. In: *Production and Operations Management* 1.14, pp. 35–52.

Hudnurkar, M., S. Jakhar, and U. Rathod (2014). “Factors affecting collaboration in supply chain: a literature review”. In: *Procedia-Social and Behavioral Sciences* 133, pp. 189–202.

Kubicek, H. (1976). *Heuristische Bezugsrahmen und heuristisch angelegte Forschungsdesigns als Elemente einer Konstruktionsstrategie empirischer Forschung*. Stuttgart: J. B. Metzlersche Verlagsbuchhandlung und Carl Ernst Poeschel Verlag GmbH.

Kumar, N., L. K. Scheer, and J.-B. E. M. Steenkamp (1995). "The effects of perceived interdependence on dealer attitudes". In: *Journal of Marketing Research* 3.32, pp. 348–358.

Kwon, I. W. G. and T. Suh (2005). "Trust, commitment and relationships in supply chain management: a path analysis". In: *Supply chain management: an international journal* 1.10, pp. 26–33.

Lavie, D. (2006). "The competitive advantage of interconnected firms: an extension of the resource-based view". In: *Academy of Management Review* 3.31, pp. 638–658.

Li, G., H. Fan, P. K. Lee, and T. C. E. Cheng (2015). "Joint supply chain risk management: an agency and collaboration perspective". In: *International Journal of Production Economics* 164, pp. 83–94.

M., C., M. A. Vonderembse, Q. Zhang, and T. S. Ragu-Nathan (2010). "Supply chain collaboration: conceptualisation and instrument development". In: *International Journal of Production Research* 22.48, pp. 6613–6635.

McEvily, B., V. Perrone, and A. Zaheer (2003). "Trust as an organizing principle". In: *Organization Science* 1.14, pp. 91–103.

Miyamoto, G. R. (2007). "2007 Niigata Chuetsu-Oki Japan Earthquake Reconnaissance Report". In:

Mohr, J. and R. Spekman (1994). "Characteristics of partnership success: partnership attributes, communication behavior, and conflict resolution techniques". In: *Strategic Management Journal* 2.15, pp. 135–152.

Monczka, R. M., K. J. Petersen, R. B. Handfield, and G. L. Ragatz (1998). "Success factors in strategic supplier alliances: the buying company perspective". In: *Decision Sciences* 3.29, pp. 553–577.

Morgan, R. M. and S. D. Hunt (1994). "The commitment-trust theory of relationship marketing". In: *The Journal of Marketing* 3.58, pp. 20–38.

Mukherjee, A. (2008). "The fire that changed an industry: a case study on thriving in a networked world". In: *Pearson education*.

MunichRe (2016). "Overview natural catastrophes 2015". In: *Geo Risks Research*.

Nishiguchi, T. and A. Beaudet (1998). "The Toyota group and the Aisin fire". In: *MIT Sloan Management Review* 1.40, pp. 49–59.

Nissan (2012). "Disaster response at Nissan". In: *Sustainability Report 2012*, pp. 8–9.

Nyaga, G. N., J. M. Whipple, and D. F. Lynch (2010). "Examining supply chain relationships: do buyer and supplier perspectives on collaborative relationships differ?" In: *Journal of Operations Management* 2.28, pp. 101–141.

Olcott, G. and N. Oliver (2014). "Social capital, sense-making and recovery from disaster: Japanese companies and the March 2011 earthquake". In: *California Management Review* 2.56, pp. 5–22.

Pollack, A. (2011). "The assembly line is rolling again, tenuously, at Honda in Japan". In: *New York Times*.

Ponis, S. T. and E. Koronis (2012). "Supply chain resilience: definition of concept and its formative elements". In: *Journal of Applied Business Research* 5.28, pp. 921–930.

Ponomarov, S. (2012). "Antecedents and consequences of supply chain resilience: a dynamic capabilities perspective". In: *Doctoral Dissertation, University of Tennessee*.

Renesas (2011). "CSR and Environmental Report". In: *Renesas Electronics Corporation*.

Reuters (2016). "VW's key plant hit by parts shortage in supplier row". In:

Rice, J. B. and F. Caniato (2003). "Building a secure and resilient supply network". In: *Supply Chain Management Review* 5.7, pp. 22–30.
Rousseau, D. M., S. B. Sitkin, R. S. Burt, and C. Camerer (1998). "Not so different after all: a cross-discipline view of trust". In: *Academy of Management Review* 3.23, pp. 393–404.
Ryu, I., S. So, and C. Koo (2009). "The role of partnership in supply chain performance". In: *Industrial Management and Data Systems* 4.109, pp. 496–514.
Sheffi, Y. (2005). *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*. Cambridge, Massachusetts: MIT Press.
Sheu, C., H. Yen, and D. Chae (2006). "Determinants of supplier-retailer collaboration: evidence from an international study". In: *International Journal of Operations and Production Management* 1.26, pp. 24–49.
Simatupang, T. M. and R. Sridharan (2002). "The collaborative supply chain". In: *The International Journal of Logistics Management* 1.13, pp. 15–30.
Simchi-Levi, D., W. Schmidt, and Y. Wei (2014). "From superstorms to factory fires". In: *Harvard Business Review* 1/2.92, pp. 97–101.
Stecke, K. E. and S. Kumar (2006). "Sources of supply chain disruptions, factors that breed vulnerability, and mitigating strategies". In: *Journal of Marketing Channels* 3.16, pp. 193–226.
SwissRe (2015). "Natural catastrophes and man-made disasters in 2014: convective and winter storms generate most losses". In:
Thun, J. H. and D. Hoenig (2011). "An empirical analysis of supply chain risk management in the German automotive industry". In: *International Journal of Production Economics* 1.131, pp. 242–249.
Tukamuhabwa, B. R., M. Stevenson, J. Busby, and M. Zorzini (2015). "Supply chain resilience: definition, review and theoretical foundations for further study". In: *International Journal of Production Research*, pp. 1–32.
Voss, C., N. Tsikriktsis, and M. Frohlich (2002). "Case research in operations management". In: *International Journal of Operations and Production Management* 2.22, pp. 195–219.
Wai, L. C. and W. Wongsurawat (2013). "Crisis management: Western Digital's 46-day recovery from the 2011 flood disaster in Thailand". In: *Strategy and Leadership* 2.41, pp. 34–38.
Whitney, D. E., L. J., and H. D. A. (2014). "The benefits and constraints of temporary sourcing diversification in supply chain disruption and recovery". In: *Journal of Purchasing and Supply Management* 4.20, pp. 238–250.
Wieland, A. and C. M. Wallenburg (2013). "The influence of relational competencies on supply chain resilience: a relational view". In: *International Journal of Physical Distribution and Logistics Management* 4.43, pp. 300–320.

Automotive Supply-Chain Requirements for a Time-Critical Knowledge Management

Ann-Carina Tietze[1], Jan Cirullies[2], Boris Otto[2]

1 – Volkswagen Commercial Vehicles; TU Dortmund

2 – Fraunhofer Institut für Software- und Systemtechnik ISST

Transforming increasingly growing data volumes into knowledge and improving its usage requires knowledge management models (KMM). KMM structures the workflow for decision taking based on knowledge. Industry-suitable requirements for a KMM, in particular for automotive supply chains (SC) and supply-critical bottlenecks, are not raised, especially concerning the crucial parameter of time-criticality. As none of the investigated models suits time-related specifications, requirements for time-critical knowledge management (KM) are derived from former case studies (CS) in the manufacturing automotive industry by literature research. These requirements will be used to evaluate existing KMM proposed in literature. Requirements for a KMM, which supports the manufacturing automotive industry (AI) in time-critical cases, are collected from practice by means of group discussions, generalised, abstracted and verified such as real-time capability, availability and accessibility, incentives for knowledge-sharing or intuitive handling. In particular, it addresses the application case of a supply-critical bottleneck in the inbound logistics. This results in rethinking of knowledge as a fundamental, time-critical resource for the reduction of supply risks. Currently, there are neither KMMs that involve time-criticality supporting industry to deal with increasing data and knowledge volumes nor precise requirements for time-critical KM in case of a supply-bottleneck in the AI. The importance of time-critical knowledge in contrast to mere data is shown. Finally, time-criticality is highlighted by showing its value to minimise production-breakdown-risks. The aim is to raise awareness about the need for changes in existing processes in the AI and to define the scope of scientific research needs.

Keywords: time-critical knowledge management; bottleneck management; automotive industry requirements; case study research

1 Introduction

Knowledge and fundamental data have, as a key success factor to the creation of competitive advantages, placed their importance as significant and precious resources in the management ideas of the AI. Fashionable concepts such as Big Data and Industry4.0 are an integral part of the company environment. Data is collected and stored which makes the data volume grow exponentially. This poses new challenges for the AI, as the collected data has to be useable and applied to generate and to disseminate knowledge. It is becoming increasingly clear that the collection and storage of large amounts of data only helps if it is not understood as a self-purpose, but the use of this data is paramount.

What is the role of time? Time as a success factor for the competitive advantages of producing companies in the AI is fundamental: the production times of individual products, as well as the delivery times of suppliers and to customers must always be reduced. Innovations must be brought rapidly to market; the products are subject to constant change. The consumer adapts to these shortened cycles and expects a constant stream of innovations. True to the motto of Rudolf von Bennigsen-Foerderer (1923-89) ”Standstill is a step back” (Buchenau, 2016, p.191), the industries do their utmost to promote change. The bulk of the information used in the AI is not static, but rather time-critical, flexible and changeable. A KMM, which takes knowledge as static, fixed quantities, may not meet the requirements of the industry and, rather than help, delay, unsettle and thus create risks for the supply of the production.

The use of collected data results in the necessity of integrating time-criticality into KMMs. In the course of this, the requirements for such a time-critical KMM have to be determined and presented in the manufacturing AI. These requirements thus form the basis of a KMM which is adapted to current needs of the AI for the optimal use of collected data in the form of knowledge.

The target of this paper is to define precise requirements for a KMM from the AI that are not yet fulfilled by existing KMM. Their suitability for the industrial environment of the AI, especially in time-critical fields, is the focus of the investigation. The central aspect is the application of a supply-critical bottleneck. The structure of the work provides for an examination of the theoretical and practical problem background in chapter 2, followed by a description of the methodological procedure in chapter 3. Empirical analyses in the form of the inclusion of investigative CSs, whose findings are cumulatively evaluated, are used to meet requirements with the objective of providing comprehensive knowledge of time-critical information. Chapter 4 deals with the implementation and the findings, followed by the evaluation (chapter 5). The special requirements of the subjects are abstracted and generalised. The work concludes with a summary in chapter 6.

2 Theoretical Perspectives on Knowledge Management

2.1 Difference between Knowledge and Data in Literature

Despite the frequently erroneously synonymous use of the terms ”data”, ”information” and ”knowledge” in everyday usage, there are serious differences in the actual meaning, which makes a delimitation of the terms necessary.

Signs form the basis. Data includes arbitrary strings and value is assigned to the character by syntax. Through collusion on specific characters and strings, the user is able to recognise the contents of data. As soon as the data is linked together and a causal link is assigned to them in form of semantics, they become information (Bodendorf, 2006, pp.1-2; North, 2011, pp.36-37). Use of information in this context already means the generation of knowledge which is understood to mean the networking of information with the objective of using and applying it purposefully. In order to connect and interpret information in the correct, meaningful and effective manner, it is often necessary to have prior knowledge that the user either already possesses or has to acquire (Bodendorf, 2006, pp.1-2; North, 2011, pp.36-37; Nikodemus, 2017, pp.83-86).This leads to the conclusion that knowledge includes not only the networking of information but also experiences and knowledge, abilities and skills, values, know-how and qualifications (Nikodemus, 2017, pp.85-86).

This distinction also is highly relevant today as it corresponds to the Industry 4.0 Maturity Index, a recent study from catech, which describes the digital transformation of companies. The acatech industry 4.0 Maturity Index serves as a guide for companies interested in advancing their degree of digitalisation and is build up as a six stepped model: ”computerisation” and ”connectivity”, which form together the group ”digitalisation”, ”visibility”, ”transparancy”, ”predictive power” and ”adaptability”, which form the category ”Industry 4.0” (Schuh et al., 2017, pp.15-18). These model levels are in line with the knowledge pyramid of Bodendorf (2006) as they represent a detailing and extension of it. ”Signs” have to be reconciled with the ”digitalisation”. This is followed by the ”data” level, which is equivalent to ”visibility”: ”What happens?” A causal link follows in the next step, the ”transparency”. A forecast for the future, which is possible only by means of knowledge, completes the model for the Industry4.0 Maturity Index.

2.2 Knowledge Management in Automotive Industrial Environment

In the AI, data is collected and used in large quantities. However, this development is often still at an early stage, so that not all potentials are fully exploited: knowledge is collected, but not processed; processed, but not linked; linked but not communicated. In a company, knowledge is often only present within certain fields and is not shared by either the system or the employees of different departments. The transition from implicit to explicit knowledge is often interrupted (cf. section 2.3.1). This makes the integration of a new KM in companies necessary.

2.2.1 Special Case: Time-Criticality

KM as a necessary concept for a modern company organisation is not a new approach (Born, 2009; Lakshman and Parente, 2008; Jane Zhao and Anand, 2009). However, one important factor is missing: the time. It plays an important role in the manufacturing industry. True to the principle of ”time is money”, time is a great influence on competitiveness, securing the market position as well as the size of the output and productivity. A KM concept for the industry has to consider and integrate this factor. The time-criticality includes on the one hand time-critical processes and a time-critical information provision, on the other hand also time-critical information.

2.2.2 Bottleneck-Management in the Automotive Industry

This chapter is an excerpt from practice in the form of an experience report.

In the AI a distinction is made between bottleneck-management, which aims to prevent bottlenecks on the production proactively, and the bottleneck-control, which takes place after the occurrence of a supply-critical bottleneck and deals with the regulation and distribution over affected plants (reactive).

Bottleneck-management is a particularly illustrative application for a time-critical KM. Within the scope of capacity management, the supply assurance of the production is checked at regular intervals. For this purpose, the production capacity provided by the supplier is compared with the parts requirements determined by the Original Equipment Manufacturer (OEM). Since these needs and capacities vary according to the order, to the machine utilisation, shift models and holidays, a system determines ”secured” and ”unsecured” weeks by comparison. Identified ”unsecured” weeks will be investigated in the daily hedging process, so that risks can be ruled out at an early stage.

However, the supplier often suffers short-term supply disruptions, for example due to political unrest, natural catastrophes or financial disasters. In these cases, rapid action is crucial in order not to endanger production. Manual data is collected along the SC. Contact persons are identified and get informed. An internal team consisting of procurement, logistics and partial quality assurance is compiled and contacts the supplier in regular telephone conferences. For these conferences, data is collected in advance. This proves to be difficult because of the person-dependent limitation with regard to data’s availability: information on logistics, procurement and quality assurance is only disclosed to the other involved parties in order to deal with the time-critical situation in the best possible way. The manual effort to receive the message with regard to a supplier-critical situation at the supplier up to the time the SC and the contact persons are known and all relevant data for the management of a supply-bottleneck, is enormous and can take an average of up to a week. In a time-critical supply-bottleneck, one week could be the cause for a production breakdown and profit loss. Therefore a time-critical KMM is needed, which helps to deal with acute knowledge in time-critical situations which are of paramount importance.

2.3 Knowledge Management Models

A literature review for KMM by using the keyword ”knowledge management” yields numerous hits. Adding the keyword ”time-critical” has no useful result. For this reason, a further literature review for time-critical KM is not effective. Nevertheless, this chapter will provide an overview of the core idea of KM but will not give a summary of all KMM. The models generally deal with the process of generating and disseminating knowledge. Some of these models address theoretical approaches to deal with knowledge, for example knowledge-based theory or competence-based theory (Martensson, 2000, p.205). Others do not integrate industrial but individual requirements (Reinmann-Rothmeier and Eppler, 2008). The third category identifies requirements of industry and abstracts these in the form of business driven KMM.

From the third group, three models will be presented, which are covering a wide spectrum and are the basis for many other models, just like North (2011), Gronau (2009) or Nikodemus (2017). The SECI-model from Nonaka and Takeuchi (1997) is one of the fundamental models for the understanding of KM today. Probst, Raub and Romhardt (2012) take up further industry requirements and expand the SECI-model. Their approach to anchoring KM in the industry becomes apparent. The "Magical Triangle of KM" is presented as the third model. This model takes on other requirements of industry and attempts to abstract and generalise them (Gehle, 2006; Rücker, 2002).

2.3.1 SECI-Model by Nonaka and Takeuchi

Nonaka and Takeuchi distinguish between explicit and implicit knowledge. Explicit knowledge means written knowledge, which can be easily transmitted. In contrast, implicit knowledge is only available to the knowledge carrier, often unconsciously. It is hard or impossible to be transferred (Nonaka and Takeuchi, 1997, p.75).

According to Nonaka and Takeuchi (1997, p.75) these two types of knowledge can be transformed in the form of a continuous knowledge spiral, thus generating knowledge. Four successive phases are performed regularly:

- Transformation from implicit to implicit knowledge is called Socialisation. It means the acquisition of individual, implicit knowledge.
- Transformation from implicit to explicit knowledge is called Externalisation. It describes the documentation of implicit knowledge to become explicit.
- Transformation from explicit to explicit knowledge is called Combination and means the arrangement of the new explicit knowledge with already existing explicit knowledge.
- Transformation from explicit to implicit knowledge is called Internalisation and refers about the assimilation of new knowledge and becoming implicit knowledge.

This means that individual knowledge can be transferred to an ever-increasing organisational level within an organisation, making it accessible. Nonaka and Takeuchi (1997, p.75) have thus created a general model that helps for example in a company, to develop and multiply knowledge, and thereby to manage the generation of knowledge.

This model is therefore a basis for the understanding of the generation of knowledge, which is also applied in companies, but the time factor is not integrated. Time-critical knowledge is treated according to this model as well as time-uncritical. The model must therefore be adapted to the industry.

2.3.2 Knowledge Circulation by Probst, Raub and Romhardt

Probst, Raub and Romhardt (2012) proceed inductively from the requirements of the industry and abstract their results in a model. There are six problem categories that influence each other and, according to Probst, Raub and Romhardt (2012, pp.30-33), are the core processes of KM. The process of knowledge identification is intended to create transparency about internally and externally available knowledge, the process of knowledge acquisition addresses the question of the acquisition of new knowledge outside the organisation. Complementary to this is the process of knowledge development, which focuses on building new internally and externally knowledge. The knowledge sharing involves the transfer of knowledge to the right place, while the knowledge exploitation ensures the productive use of organisational knowledge. The knowledge preservation takes care of the protection against loss of knowledge. In addition, they introduce two further categories that are intended to anchor the importance of knowledge in the company: the knowledge objectives which define the direction of learning, as well as the knowledge validation for the measurement of learning success (Probst, Raub and Romhardt, 2012, pp.30-33).

New to this model is the focus on the requirements of the industry, which are necessary to implement the model in practice. However, the time factor is also not integrated in this model.

2.3.3 ”Magical Triangle of Knowledge Management”

The magic triangle of KM is widely discussed in the literature (Gehle, 2006, p.11; Rücker, 2002, p.32). All however address the approach of adapting KM to the needs of the industry by integrating the fields of "employee/culture/personnel management", "organisation/processes" and "information and communication technology" (Gehle, 2006, p.11; Rücker, 2002, p.32). This is intended to create an interdisciplinarity of KM, which is necessary for the establishment in practice (Probst, Raub and Romhardt, 2012, p.259).

In detail, this means that transparent business processes and decision-making structures, as well as training and incentives to increase knowledge are necessary. Appropriate technical preconditions must also be created (Rücker, 2002, p.32). Nevertheless, the time-criticality of knowledge is not mentioned in these models.

2.4 Need for Action

Data as a resource of the present time implies the construction of large data volumes and also requires KM, which helps to make the collected data usable. There are numerous models that deal with the generation of knowledge. Their suitability for the AI is limited, because they do not take the factor of time-criticality of knowledge and information into account.

The volume-adequate supply of the production with parts in a supply-bottleneck depends decisively on the handling of time-critical knowledge. The result is a time-critical KMM, which is adapted to industrial needs. As a basis for this, requirements for a time-critical KM have to be collected, compared and assessed from industry and science. In order to produce a representative image of reality, the requirements are gathered from several group discussions conducted in loops, which are based on the application of bottleneck-management. These practical requirements represent the starting point for further deepening with scientific research focus.

3 Methodological Approaches for the Development of Time-Critical Knowledge Management: Case Studies

3.1 Research Method Selection and Types of Designs

CSs from literature are compared with a newly recorded CS and requirements for a time-critical KM in the manufacturing AI are derived. The inclusion of CSs shall ensure a high degree of practical relevance and timeliness (Gehle, 2006, p.16). It is a qualitative research approach that is applied when complex, little explored fields of interest are considered with contextual relevance. It has the advantage that hypotheses can be derived from the practice which are verified and validated with the help of literature. This leads to new perspectives and results in a new insight and the development of new knowledge (Borchardt and Göthlich, 2009, p.46).

Following YIN (2014, pp.49-50), an embedded single-case study is presented. The bottleneck-management is used as a relevant context in the time-critical supply-bottleneck, and the different fields involved in the internal and external management are used as analysis objects.

3.2 Data Collection Method

CSs as a qualitative research method allow a variety of data collection methods (Riesenhuber, 2009, pp.6-7). According to Borchardt and Göthlich (2009, p.38), these can be divided into three categories: observation, questioning and content analysis, which differ in their approach.

The observation shows a rather passive, non-participating basic idea. Information is collected, not determined (Borchardt and Göthlich, 2009, p.38).

The survey is of a reactive nature as participants react to the directly respondent (Weber, 2009, p.147; Riesenhuber, 2009, p.12). Differentiation will be made in individual interviews, which may be personal, by telephone or in writing, and group interviews. Depending on the application, the construction is structured, partially structured or unstructured. The choice of the method depends on the application, the research question and the result to be achieved. Complex, poorly researched fields often require semi-structured interviews, which only slightly limit the possible answers. In contrast to this, a structuring is advantageous in a specific questioning, which leads to focused responses (Lamnek, 2002, p.173; Meuser and Nagel, 1991, pp.448-449).

A special form of the group interview is the group discussion. It is particularly concerned with the interaction of the group members (Fay, Garrod and Carletta, 2000, p.481; Vogel, 2014, p.581). The framework of the discussion is provided by a guideline, which supports to focus on the research topic. It includes the framework theme as well as a few individual aspects (Dammer and Szymkowiak, 1998, pp.94-95; Vogel, 2014, p.583). This method has a rather unstructured character, but it also allows a great gain in knowledge. The participants inspire each other with opinions, insights and new ideas. The interplay in a group on a particular research subject enables knowledge that is not possible through individual queries of prefabricated questionnaires (Müller, 2008, p.5; Vogel, 2014, p.582). This enables existing hidden problems and potentials to be uncovered, which the individual is not aware of or with which he has arranged himself. An advantage of this method is, on the one hand, the breaking open of fixed views and ideas; on the other hand the collective orientation can be worked out. The influencing of the participants can be disadvantageous, just as the hindrance of individual expressions of opinion due to adaptation mechanisms (Frey, 2007, p.3; Vogel, 2014, p.582).

The content analysis as the third category according to Borchardt and Göthlich is based on observations and interviews, and supplements them with information based on documents and data sets. It is thus a summary and explanation (Borchardt and Göthlich, 2009, p.38).

3.3 Further Requirements of the Method

The selection of the participants is crucial for the quality of the results. Rack and Christophersen (2009, p.28) point out that there may be differences in the survey results, depending on whether the participants participate voluntarily or involuntarily in the survey.

In group interviews or group discussions, the group's composition is also of interest. A distinction exists between real or artificial groups and homogeneous or heterogeneous groups. The former are more realistic in comparison to the latter and have a homogenous background, but are often also restricted in the openness of the discussions. In group discussions, the optimal group strength is between six and ten participants (Liebig and Nentwig-Gesemann, 2009, p.105; Vogel, 2014, p.581-584).

The optimal quantity of discussions depends on the theoretical saturation. As soon as a new survey or discussion does not bring any added value to the findings, this saturation is achieved and thus the optimal quantity of interviews or discussions (Vogel, 2014, p.584).

4 Case Study from Industrial Practice and Requirements in Literature

The method of the CS is chosen to create an image of reality and to deduce inductively from the requirements of practice to the theory behind it. Group discussions as survey methods should promote the creativity of respondents. In order to break down established behavioral patterns and perspectives in the first step, which can only be identified by the interaction in the group, this method is very suitable.

4.1 Object of the Survey

The object of the survey is a multinational large group of the AI, headquartered in Germany. A practical CS is taken as a use case. The application of a supply-critical bottleneck by the manufacturing AI provides the framework conditions for the extent of the CSs taken.

All priority fields involved in a time-critical lack of material are surveyed as shown in figure 2. Therefore, their requirements for a time-critical KMM are recorded and then compared with each other. The requirements of the participants are used to derive abstracted, generally valid requirements for time-critical KM for volume-critical supply-bottlenecks in the AI.

4.2 Process, Participants and Timeframe

The method of group discussion is applied on the basis of suitability for the present application. The target is to uncover hidden potentials in bottleneck-management, which are unaware of the individual. Further advantages in the benefit of group dynamics lie in the integration of all involved parties to increase the motivation as well as the promotion of creativity. A guide is limited to the theme of bottleneck-management and defines the calls to discuss the process, to highlight obstacles, to uncover information gaps, and to present personal requirements to an "optimal" process.

The participants are selected on the basis of the need for motivated and committed participants on a voluntary basis. All those involved in the bottleneck-management application are invited to participate in the group discussion.

Due to the assignment to specific subject areas, they are homogeneous real groups with a range of between six and ten participants. Group-wide employees in the fields of procurement and logistics are surveyed in three large companies in the AI (OEM) as well as in an international medium-sized supplier. In total, 10 discussions are held with a total of 35 participants and, in order to ensure the anonymity of the participants, the results of the evaluation are not broken down into the fields involved.

4.3 Procedure of the Group Discussions

The discussions lasted a period of five months in the first half of 2017. The initial question, which can be seen in figure 1, is set independently for each group. To answer this question, group discussions take place. It is only in this discussion that disclosure of existing potentials is possible since the group participants are partly challenging each other by their different perceptions, partly confirming each other by their same perceptions. The contents of the discussion topics as well as the results of the discussions are documented in short protocols. Subsequently, the results are clustered and submitted to the group participants again. The group itself analyses and evaluates the results. It prioritises certain topics and places the importance of others in the background, as shown in figure 1. The clusters of results are prioritised in high potential, coloured dark grey, and low potential (light grey).

4.4 Findings from the Bottleneck-Survey

The "lived" bottleneck-process is shown in figure. In most cases, the supplier provides the first information regarding a supply risk. Depending on the risk

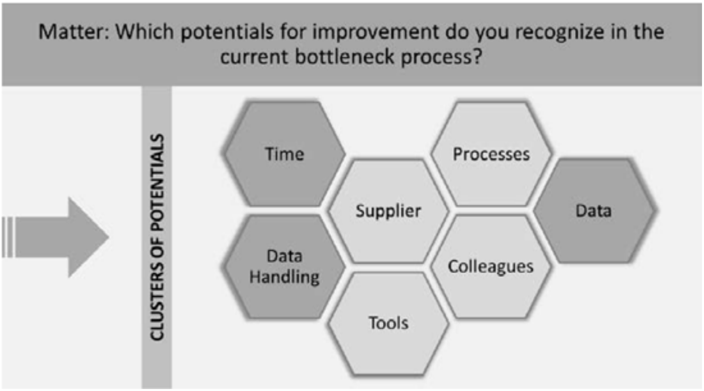

Figure 1: Clusters of potentials for the bottleneck-process in the AI

location within the SC, this information can take several days to reach the right contact person at the OEM, the responsible buyer in the normal case.

The latter then provides information on logistic and procurement, as shown in figure 2, as well as on the development of the individual brands and plants concerned. Together, they set up a team, which exchanges itself by telephone with the responsible supplier. The necessary information is determined on the basis of the system's access to the individual areas. Further information is collected manually.

A range-wide monitor correcting acute requirements with current stock allows the available parts to be allocated to the plants. If the SC is filled again and the delivery call can be operated again, the control process is passed on.

The obstacles in the current bottleneck-process are identified. The necessary manual recording of information is a great deal of time and effort for the editor. In addition, the distribution of information via e-mail by missing contact persons in the mailing list and misdirected or non-sent mail represents a major obstacle in the processing of bottlenecks. Another barrier is missing and limited access rights to information and systems. In addition, trust in the systems is limited due to faulty or obsolete data. It would be helpful to know the SC. However, these data are not available and cannot be determined due to legal restrictions in the

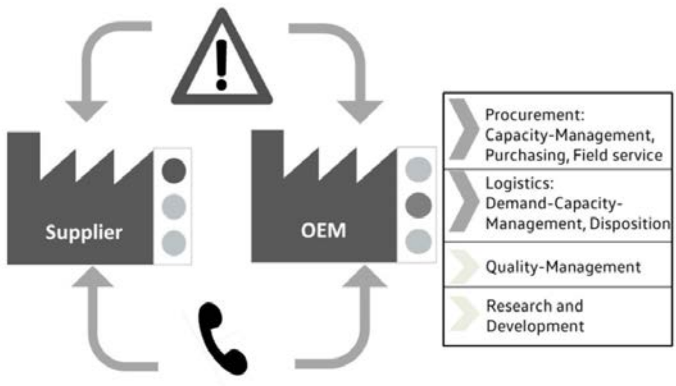

Figure 2: Bottleneck-process including the integrated departments

individual case. As a result, contacts are also lacking along the SC, which in the event of a bottleneck might have the potential to ease the situation.

5 Abstraction and Evaluation of Requirements for Time-Critical Knowledge Management

5.1 Derived, General Requirements

The described obstacles lead to requirements for bottleneck-management which can be divided into three priority categories: Requirements for data, for handlings and for time, as shown in figure 1. Requirements for the category "time" are not broken down in detail since this paper generally deals with the requirements for time-critical KM. As a result, only two priorities remain.

5.1.1 Requirements for Data

The results of the group discussions can be summarised as follows with regard to the requirements for a time-critical KM:

Actuality of data

Time-critical knowledge requires real-time, up-to-date information. An outdated state of data can lead to incorrect decisions in specific situations, since a time-critical process requires quick decisions.

Probst, Raub and Romhardt (2012, p.217) define the actuality of data as a basis for data quality. They justify this approach, for example, with high costs for investment decisions based on outdated information (Probst, Raub and Romhardt, 2012, p.217). North (2011, p.52) also refers to the actuality of information bases. Weber and Berendt (2017, p.28) even note that a system cannot be used without a suitable data update.

Timely availability of data

In time-critical situations requiring rapid action, requested data must be immediately available. Any additional time required to find the information means that there are temporal and thus monetary losses.

North (2011, p.52) points out that time and place are the availability of knowledge-determining factors. Time differences due to global companies may not affect the availability of information.

Local availability and accessibility of data

Information must be accessible to everyone involved. In addition, it is necessary that all involved parties, regardless of their location, are informed.

According to North (2011, p.52), a local availability of data is to be taken into account especially in globally operating companies.

Quality of data

In the time-critical case, the quality of data is important, in particular, the completeness, authenticity and resilience of the information. In the case of poor information quality, optimal decisions cannot be made. Trust in the use of available data would decrease.

Probst, Raub and Romhardt (2012, p.205) declare the quality of information as crucial for databases, since databases with irrelevant data lead to mistrust and consequently to a reduced or lack of use.

5.1.2 Requirements for Handling

Trust and silo mentality

The exchange of knowledge depends to a great extent on the willingness to cooperate between the parties involved. A ”silo mentality” creates boundaries. Trust among each other and a breakup of silo thinking is therefore indispensable.

Probst, Raub and Romhardt (2012, p.127) mention the problem of the formation of inefficient knowledge bases in organisations with high communication barriers. The keys to collective knowledge creation are, according to Probst, Raub and Romhardt (2012, p.127), interaction, communication, transparency and integration.

Means of communication

A network of all participants creates the conditions for a targeted exchange of information. The means of communication must be accessible to everyone involved. They must also provide a framework appropriate to the application and generation.

According to Probst, Raub and Romhardt (2012, p.127) the success of organisations the individual knowledge of the individual can be less helpful than the knowledge between the individual, the dependencies and relationships. These relationships can only be established and maintained through interaction and communication. North (2011, p.52) puts the factor of communication in the generation of knowledge in the foreground by focusing on a personal learning of the participants.

Motivation

Incentives are needed that motivate the participants to share their knowledge and experience. This can take the form of a change in corporate culture, in which knowledge is rewarded and not the restraint of knowledge with the target of becoming irreplaceable. Another possibility consists in the approach of the Gamification of the work (Heilbrunn and Sammet, 2017, p.83).

An increased commitment by all parties involved in the implementation of common goals can be achieved through motivation (Probst, Raub and Romhardt, 2012, p.60). In the case of a lack of motivation, a transfer of knowledge is made more difficult (Probst, Raub and Romhardt, 2012, p.170).

5.2 Evaluation of Generalised Requirements

Even if the identified requirements are justified by the expert's knowledge of the group discussions, it is necessary to analyse the hurdles that the requirements have currently failed in order to allow a reduction.

The actuality of data

Data must be up-to-date and available in real-time. For this purpose, a networking of all source systems according to a suitable structure is necessary. Constant updating of certain records is required.

Timely availability of data

The information supply must be supported on the IT side in order to avoid temporal losses due to analogue information procurement.

Local availability and accessibility of data

Unrestricted access of all parties to necessary, existing data is essential. For this, a suitable tool must be available to each participant. Unrestricted communication is necessary. Access permissions for specific data headers must be extended.

Quality of data

In order to ensure high data quality, a validation of the information takes place in advance. This is possible, for example, by evaluating the reliability of the source system.

Trust and silo mentality

There has to be no holding on to old structures but openness for new solutions. An integration of all stakeholders is indispensable.

Means of communication

The means of communication must be accessible to everyone involved. They must also provide a framework appropriate to the application and generation.

Motivation

One possibility is the approach of gamification at work (Heilbrunn and Sammet, 2017, pp.85-87). It is an incentive from within. The work and especially the use of tools should be fun and therefore promote motivation. Another approach is a change in corporate culture. This is an incentive from outside, by rewarding knowledge and not by restraining knowledge with the aim of becoming irreplaceable.

5.3 Evaluation of Methods

The models of KM discussed in chapter 2.3 do not cover the requirements of industrial practice in the AI in a time-critical situation. In order to encounter this, it is necessary to deduce, outgoing from the requirements of the practice, knowledge and to transfer it into the theory. The CS is the appropriate methodology to illustrate the complexity of the practice and make it tangible. Through the inclusion of expert knowledge by group discussions, an enormous return of know-how from practice to theory is possible.

Nevertheless, it should be noted that the extent of the CS can be expanded by extending a questionnaire regarding the number of participants as well as the number and structure of questions.

A full evaluation of the added value of the methodology and the results is only possible if the identified requirements are transferred to a KMM and this model is applied in practice.

5.4 Limitations

This paper describes the basis for an adapted KMM for the structuring of knowledge. These are the items that provide a guide. The requirements are particularly applicable in the AI and cannot be fully applicable to other industries and companies. The requirements determined by surveys of a wide range of different automotive manufacturers are intended to become a general invalidity which, however, has gaps for limiting the selection.

The described case of handling time-critical knowledge in the application of the supply-critical bottleneck-management of the AI places special emphasis on the requirements in the time-critical case. These requirements may differ in the absence of time-criticality.

In addition, it will not be sufficient to rely solely on a KMM in the time-critical supply-risk. Such a model may support, but cannot replace the experience of the employees.

6 Conclusions

The present work shows that there are numerous, partly unused sources of knowledge in the AI that must be prepared and used. This is conceivable in the form of a KMM. However, literature currently lacks KMM that integrate the requirements of the time-criticality of data and processes. They are not optimally adapted to the needs of the industry.

The subdivision of the requirements (cf. figure 3) consists of two classes and depicts two fields of action: On the one hand, an optimisation of data structures is necessary in order to provide an up-to-date, complete and high-quality providing of the user's information to the users. This includes the adapted networking of data sources and the restructuring of the current network, as well as making the information accessible to all participants in the form of timely, adapted tools. On the other hand, a change in the corporate culture away from silo mentality and to the idea of a team is also a matter of cross-company activity.

However, there are further research needs. The requirements are the basis for a time-critical KMM. It is therefore necessary to analyse further models and to reconcile them with the identified needs of the industry. Hence, an adaptation of existing models is required. It should be noted that an adapted model is not sufficient for applicability in industry alone. Structuring the generated knowledge is necessary, for example in the form of an information object model.

In addition, a comprehensive analysis of the motivation factors of the users is essential, which is fundamental for the implementation and integration of a time-critical KM.

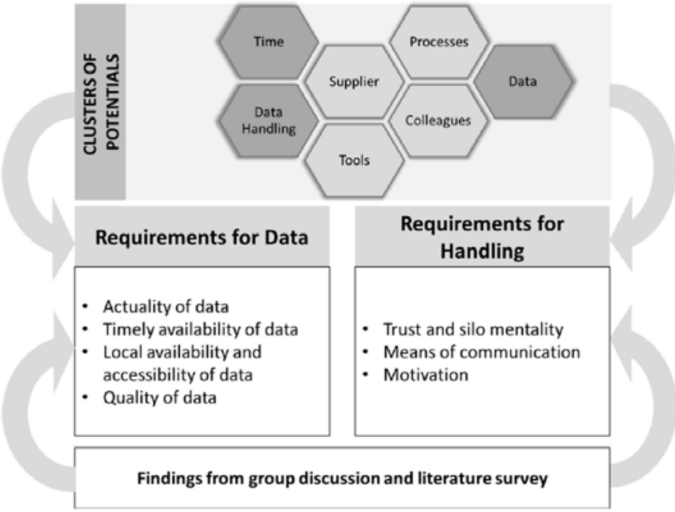

Figure 3: Conclusion of the determined requirements of the AI for time-critical KMM

References

Albers, S., D. Klapper, U. Konradt, A. Walter, and J. Wolf, eds. (2009). *Methodik der empirischen Forschung*. 3., überarbeitete und erweiterte Auflage. Wiesbaden and s.l.: Gabler Verlag.

Baur, N. and J. Blasius, eds. (2014). *Handbuch Methoden der empirischen Sozialforschung*. Wiesbaden: Springer VS.

Bodendorf, F. (2006). *Daten- und Wissensmanagement*. 2., aktualisierte und erweiterte Auflage. Springer-Lehrbuch. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Borchardt, A. and S. Göthlich (2009). “Erkenntnisgewinnung durch Fallstudien”. In: *Methodik der empirischen Forschung*. Ed. by S. Albers, D. Klapper, U. Konradt, A. Walter, and J. Wolf. Wiesbaden and s.l.: Gabler Verlag, pp. 33–48.

Born, V. (2009). *Problemorientiertes Wissensmanagement in der Automobilindustrie: Ein interdisziplinärer Ansatz*. Wiesbaden: Gabler Verlag / GWV Fachverlage GmbH Wiesbaden.

Buchenau, P., ed. (2016). *Chefsache Gesundheit II: Der Führungsratgeber fürs 21. Jahrhundert*. 1. Aufl. 2016. Wiesbaden: Springer Gabler.

Dammer, I. and F. Szymkowiak (1998). *Die Gruppendiskussion in der Marktforschung: Grundlagen - Moderation - Auswertung Ein Praxisleitfaden*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Fay, N., S. Garrod, and J. Carletta (2000). “Group discussion as interactive dialogue or as serial monologue: the influence of group size”. In: *Psychological science* 11.6, pp. 481–486.

Frey, F. (2007). *Die Gruppendiskussion als Instrument der Datenerhebung in der Marktforschung*. Grin Verlag.

Garz, D. and K. Kraimer, eds. (1991). *Qualitativ-empirische Sozialforschung: Konzepte, Methoden, Analysen*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Gehle, M. (2006). *Internationales Wissensmanagement: Zur Steigerung der Flexibilität und Schlagkraft*. Deutscher Universitts Ver.

Gronau, N. (2009). *Wissen prozessorientiert managen: Methode und Werkzeuge für die Nutzung des Wettbewerbsfaktors Wissen in Unternehmen*. München: Oldenbourg.

Heilbrunn, B. and I. Sammet (2017). “G-Learning- Gamification im Kontext von betrieblichem eLearning”. In: *Gamification und Serious Games*. Ed. by S. Strahringer and C. Leyh. Edition HMD, pp. 83–94.

Jane Zhao, Z. and J. Anand (2009). “A multilevel perspective on knowledge transfer: Evidence from the Chinese automotive industry”. In: *Strategic Management Journal* 30.9, pp. 959–983.

König, E., ed. (2002). *Qualitative Forschung: Grundlagen und Methoden*. 2., völlig überarb. Aufl., Dr. nach Typoskript. Vol. 8218. UTB. Weinheim u.a.: Beltz.

Kühl, S., ed. (2009). *Handbuch Methoden der Organisationsforschung: Quantitative und qualitative Methoden*. 1. Aufl. Wiesbaden: Verl. für Sozialwiss. / GWV Fachverl.

Lakshman, C. and R. C. Parente (2008). “Supplier-Focused Knowledge Management in the Automobile Industry and Its Implications for Product Performance”. In: *Journal of Management Studies* 42.2, pp. 317–342.

Lamnek, S. (2002). “Qualitative Interviews”. In: *Qualitative Forschung*. Ed. by E. König. Vol. 8218. UTB. Weinheim u.a.: Beltz, pp. 157–193.

Liebig, B. and I. Nentwig-Gesemann (2009). “Gruppendiskussion”. In: *Handbuch Methoden der Organisationsforschung*. Ed. by S. Kühl. Wiesbaden: Verl. für Sozialwiss. / GWV Fachverl., pp. 102–123.

Mårtensson, M. (2000). "A critical review of knowledge management as a management tool". In: *Journal of Knowledge Management* 4.3, pp. 204–216.

Meuser, M. and U. Nagel (1991). "ExpertInneninterviews: vielfach erprobt, wenig bedacht : ein Beitrag zur qualitativen Methodendiskussion". In: *Qualitativ-empirische Sozialforschung*. Ed. by D. Garz and K. Kraimer. Wiesbaden: VS Verlag für Sozialwissenschaften, pp. 441–471.

Müller, F. (2008). *Die Gruppendiskussion als Instrument der qualitativen Marktforschung und derenAnwendung im Rahmen einer vergleichenden Analys zwischen physischem und digitalem Musikgeschäft*. Grin Verlag.

Nikodemus, P. (2017). *Lernprozessorientiertes Wissensmanagement und kooperatives Lernen: Konfiguration und Koordination der Prozesse*. AKAD University Edition.

Nonaka, I. and H. Takeuchi (1997). *Die Organisation des Wissens: Wie japanische Unternehmen eine brachliegende Ressource nutzbar machen*. Frankfurt Main u.a.: Campus-Verl.

North, K. (2011). *Wissensorientierte Unternehmensführung: Wertschöpfung durch Wissen*. 5., aktualisierte und erw. Aufl. Lehrbuch. Wiesbaden: Gabler.

Probst, G., S. Raub, and K. Romhardt (2012). *Wissen managen: Wie Unternehmen ihre wertvollste Ressource optimal nutzen*. 7., überarb. und erw. Aufl. Wiesbaden: Springer Gabler.

Rack, O. and T. Christophersen (2009). "Experimente". In: *Methodik der empirischen Forschung*. Ed. by S. Albers, D. Klapper, U. Konradt, A. Walter, and J. Wolf. Wiesbaden and s.l.: Gabler Verlag, pp. 17–32.

Radermacher, F. J., ed. (2002). *Wissensmanagement: Überlebensfrage für Großunternehmen und mittelständische Wirtschaft - das magische Dreieck: Humanressourcen, Organisation und IT-Basis: Ergebnisband Ulmer Forum 2001*. Vol. 19. Wissensverarbeitung und Gesellschaft. Ulm: Universitätsverlag Ulm.

Reinmann-Rothmeier, G. and M. J. Eppler (2008). *Wissenswege: Methoden für das persönliche Wissensmanagement*. 1. Aufl. Psychologie Praxis : Lernen mit neuen Medien. Bern: Hans Huber.

Riesenhuber, F. (2009). "Großzahlige empirische Forschung". In: *Methodik der empirischen Forschung*. Ed. by S. Albers, D. Klapper, U. Konradt, A. Walter, and J. Wolf. Wiesbaden and s.l.: Gabler Verlag, pp. 1–16.

Rücker, B. (2002). "Überlebensfrage für Großunternehmen und mittelständische Wirtschaft: das neue magische Dreieck, Human Resources, Organisation und IT-Basis". In: *Wissensmanagement: Überlebensfrage für Großunternehmen und mittelständische Wirtschaft - das magische Dreieck: Humanressourcen, Organisation und IT-Basis*. Ed. by F. J. Radermacher. Vol. 19. Wissensverarbeitung und Gesellschaft. Ulm: Universitätsverlag Ulm, pp. 29–45.

Schuh, G., R. Anderl, J. Gausemeier, M. ten Hompel, and W. Wahlster, eds. (2017). *Industrie 4.0 Maturity Index: Die digitale Transformation von Unternehmen gestalten*. acatech STUDIE. München: Herbert Utz Verlag.

Strahringer, S. and C. Leyh, eds. (2017). *Gamification und Serious Games: Grundlagen, Vorgehen und Anwendungen*. Edition HMD.

Vogel, S. (2014). "Gruppendiskussion". In: *Handbuch Methoden der empirischen Sozialforschung*. Ed. by N. Baur and J. Blasius. Wiesbaden: Springer VS, pp. 581–586.

Weber, F. and J. Berendt (2017). *Robuste Unternehmen: Krisenfest in Zeiten des Umbruchs*. essentials. Wiesbaden and s.l.: Springer Fachmedien Wiesbaden.

Weber, S. M. (2009). "Großgruppenverfahren als Methoden transformativer Organisationsforschung". In: *Handbuch Methoden der Organisationsforschung*. Ed. by S. Kühl. Wiesbaden: Verl. für Sozialwiss. / GWV Fachverl., pp. 145–179.

Yin, R. K. (2014). *Case study research: Design and methods*. 5. ed. Los Angeles CA u.a.: SAGE Publ.

Bibliometric Analysis of Risk Management in Seaports

Ayman Nagi[1], Marius Indorf[1], Wolfgang Kersten[1]

1 – Hamburg University of Technology

Seaports play an essential role in global supply chains. Incidents and accidents in such ports may lead to service delays, port closure as well as damage to people, property and the environment. Therefore, risk management in seaports plays an important role in mitigating and preventing possible accidents and disruptions. This paper aims to explore the structure of literature on risk management in seaports using co-citation analysis in order to reveal its current main research areas and gaps as well as its future trends. Document co-citation analysis is performed using the organization risk analyzer (ORA) software based on a specific threshold and employing the CoCit-Score method of calculation. Suggested future research areas on risk assessment and management methods as well as cooperative risk management are revealed based on the results of the co-citation analysis.

Keywords: Risk management; Seaports; Co-citation analysis; Supply chain risk management

1 Motivation and Introduction

More than 80 percent of global trade is forwarded by sea, making maritime transport the most important mode of transport and a key enabler for international commerce and globalization (UNCTAD, 2015, p. 22). This development is the result of the continuous growth of seaborne shipments throughout the last centuries and decades. Various commodities, such as oil, gas, iron ore, or grain are shipped, totaling 10,047 million tons of cargo in 2015 which is an increase of around 200 million tons compared to 2014 (UNCAD, 2016, p. 6). Naturally, all geographic regions, e.g. the Americas, Asia-Pacific, or Europe, are involved in global seaborne trade acting as exporter and importer in different extent. In any case, the cargo is handled in large seaport facilities at the point of origin and destination. Depending on the actual route, one or more transshipment ports are utilized in order to ensure a time-saving and economic transport. Seaports connect the seaside/foreland to the hinterland, where the cargo is further transported, handled, and finally consumed.

In Europe's top 20 cargo ports 1,723.4 million tons of goods were handled in 2015 based on its gross weight. Of this amount, 1,032.5 million tons were reported on the direction inwards and 690.9 million tons were reported on the direction outwards. In total, 3,838.3 million tons of goods (2,277.6 inwards and 1,560.7 outwards) were handled in all ports of the European countries in 2015 (Eurostat, 2017, pp. 2–3). On top of this, 395.4 million seaborne passengers embarked and disembarked in all of the ports of the European countries in 2015 (Eurostat, 2017, p. 6).

These figures illustrate the significance of seaports in the area of global trade and transport. To cope with this challenge, seaports have become highly complex systems involving various actors, such as operators, authorities, crews, port workers, passengers, and the public (Andritsos and Mosconi, 2010, p. 1). In addition, seaports comprise highly specialized physical installations and facilities, operated according to demanding processes and procedures. In many cases, seaports have a unique geographical location and have developed in immediate proximity to residential areas. The port of Hamburg for example is a tidal port located at the river Elbe and is the heart of Germany's second largest city. In total, the city of Hamburg and its metropolitan region are home to more than 5.2 million inhabitants (Statistical Office of the Free and Hanseatic City of Hamburg, 2017). As a result, seaports have to fit in their surrounding community and to follow a vast number of standards and regulations in order to become and remain a safe and secure area for its internal and neighboring stakeholders.

To summarize, seaports play an essential role in modern trade and mobility and are expected to continue growing also in upcoming decades in terms of volume and complexity. At the same time, seaports have to follow strict principles and have to burden enormous efforts in order to guarantee safety and security to its bordering entities. This means, already today and even more in future seaports face an extremely difficult situation, supporting global trade on the one hand and ensuring safe and secure operations for its internal actors and its external environment. Seaports face risk challenges from operational, technical and economic perspectives (Alyami, et al., 2016, p. 10). Examples for these risks include flooding, oil spills and fire explosions (Becker, et al., 2012; Valdor, Gómez and Puente, 2015; Zhao, 2016). The only way to cope with these major challenges is to install and maintain a proper risk management in those seaports. Due to its complex nature, seaports require special risk management processes and measures that in many cases span across multiple entities and organizations.

In scientific literature, the field of risk management in seaports has been present at least since the mid-1980s and has gained increased attention throughout the last decade. In contrast to most other objects considered by risk management research, seaports rarely comprise a single organization. Thus, risk management in the field of seaports needs to address these special circumstances. Reviewing the available research on risk management in seaports, we realized the broad range of perspectives and approaches in this field. In fact, they range from very practical aspects, e.g. ballast water or oil spill treatment, to rather academic risk management frameworks serving an overarching perspective. For this reason, this paper aims to explore and to structure the scientific literature on risk management in seaports. The methodological approach chosen for this purpose is a bibliometric analysis. Focusing on co-citations in particular, we identify main areas as well as gaps in the current literature and propose future research areas in the field of risk management in seaports.

In Chapter 1, we outline the motivation for our research and provide a brief introduction to the topic. Chapter 2 frames the theoretical background on seaports as well as risk management and shapes the scope of our work. Chapter 3 elaborates the methodological approach chosen which is foremost characterized by a co-citation analysis. The results of our research are presented in Chapter 4. Conclusions based on the findings of the work undertaken are presented in Chapter 5.

2 Theoretical Background

In this section, theoretical background in the area of seaports and risk management is provided. The aspects addressed create the basis for understanding and reflecting the chosen methodology and obtained results.

2.1 Seaports as Logistical Hubs for International Trade

Seaports are very complex systems and are critical elements of the global transportation infrastructure (Christopher, 2015, p. 21). Even though seaports are immobile conglomerations of different facilities and actors with a unique geographical position, they face severe competition within the international transportation network. As a result, seaports organizations strive to meet the market requirements in the best possible fashion. In this context, it is vital to understand that a port cannot be considered as an economic unit offering or producing a single service to its customers. Instead, a broad range of processes and services is carried out in the port area (Tovar, Trujillo and Jara-Díaz, 2004, p. 190). Hence, ports in general and seaports, in particular, must be considered as a semi-structured compound of individual organizations serving a wide diversity of customers.

Apart from rather large seaports, also a number of other ports exist. In fact, ports can range from small-sized marinas servicing sport boat enthusiasts, to a mid-sized company owned and operated industrial ports to the Port of Singapore, which handles more than 1,000 vessels at any time of the day. Another dimension to categorize ports apart from their size is their primary purpose. Ports can be used for civilian, commercial or military/security purposes (Christopher, 2015, p. 27). Obviously, ports can also have hybrid forms, serving multiple purposes at the same time. In addition, the ownership structure of a port is important to consider. Generally, two main types of ownership exist in view of the port's infrastructure, superstructure, and its staff. On the one side of the spectrum, ports are owned and operated by private organizations and on the other side of the spectrum, they are part of a complex body of local, state, or national government. Very commonly, ports are owned and operated as landlord/tenant ports in which a public authority rents the port areas to private actors, such as terminal operators, whom in return pay a usage fee (Christopher, 2015, p. 27). A landlord model is also a hybrid form of a fully public and a fully private port. The paper at hand solely focusses on seaports, which we consider to be commercial ports, located directly at or in close distance to the open sea.

The processes of transporting, handling, and storing cargo in a seaport involves numerous actors. During the port entrance and exit of a ship, many shipping companies rely on the assistance of pilots and tugboat companies for safely reaching the quay wall. At the mooring, the cargo is unloaded by a terminal operator, which also forwards the cargo to storing facilities and later passes it on to carriers transporting the cargo through the hinterland. At any point in time, the processes are controlled by the port authority. Apart from the mentioned actors, several others, such as safety inspectors, customs, and repairers might be involved as well (Martino, et al., 2013, p. 125; Huber, 2014, p. 98). Apart from the different processes and services performed in a seaport, the high number of actors involved clearly drive complexity. This also underlines the importance of a thorough risk management in seaports that serve as important logistical hubs for international trade. The next section provides a brief overview of the literature on risk management in seaports.

2.2 Risk Management in Seaports

There are many definitions for risk management in the literature. For instance, Coyle, et al. (2010, p. 294) defined risk management as the process of identifying risks along with its causes and effects in order to mitigate, prevent, transfer, or eliminate possible threats to the overall supply chain success. Since seaports play a core role in global supply chains, risk management is defined in this paper as “the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole” (Jüttner, 2005, p. 124). The risk management process normally includes risk identification, assessment, handling, and monitoring of the implemented measures. (Garvey, 2008, p. 5).

Even though risk management has gained increased awareness among the actors and has become a central point of attention in a seaport, universally applicable standardized processes and measures universally applicable do not exist. In fact, up to now, risk management is very port specific in terms of scope and substance. Presumably, differing geographical and economic conditions in seaports, among many others, are the main reasons in this context. In seaports, the actors employ different risk management systems and approaches that define risk handling initiatives in the case of an emergency, such as the explosion of gases or chemicals. Apart from an intrinsic motivation to rely on suitable safety and security measures, also various guidelines and standards oblige seaport organizations to conduct a thorough risk management. These guidelines and standards exist on local, national, and global levels. A few examples are presented below.

The ISO 31000, for example, provides principles and generic guidelines on risk management that are applicable not only to seaport organizations but to any public, private or community enterprise, association, group or individual (International Organization for Standardization, 2009). Apart from such generic standards, numerous additional approaches persist. One important document is the International Ship and Port Facility Code (ISPS), which was established by the International Maritime Organization (IMO). The ISPS Code contains minimum requirements for port facilities and ship security being applied in all countries that are part of the IMO convention. One aspect of the ISPS Code is that it regulates how and to which extent a ship is required to report freight and cargo to the port which it seeks to enter (International Maritime Organization, 2003). In order to implement the ISPS Code requirements, several legal provision, such as the Maritime Transportation Security Act of 2002 in the U.S., were established. This act contains regulations specifying requirements, e.g. for security assessments or annual exercises and/or drills (U.S. Department of Homeland Security, 2003), and defines the implementation of the ISPS on a national level. In the research literature, a broad range of approaches and perspectives in the area of risk management in seaports exists. In the following, selected approaches are presented.

Focusing on container terminal operational systems Alyami, et al. (2016) present a method to facilitate the application of the Failure Mode and Effects Analysis (FMEA) in assessing the safety performance. For this purpose, they develop a hierarchical structure for risk factors during terminal operations and integrate a Fuzzy Rule-Based Bayesian Network with Evidential Reasoning. This paper strongly concentrates on the methodological approach in a locally limited environment (Alyami, et al., 2016).

The paper of Bruzzone, et al. (2000) provides the development of an integrated interactive environment for risk analysis applied to port and maritime environments. The presented approach helps to design the port and maritime infrastructure including its resources, structures, and services potentially confronted with an emergency. The architecture of the tool developed is described and is being applied by the integration of a specific simulation module to an oil spill scenario.

In contrast to the aforementioned articles, the paper of Gharehgozli, et al. (2016) proposes a conceptual framework on seaport resilience in the event of weather disruptions. The suggested approach strategically helps ports to prepare for risks associated with these potential disruptions and to design relevant contingency plans. The proposed framework consists of four steps that port managers can apply in order to increase port resilience. This paper understands ports as communities of many stakeholders and consequently has a more holistic perspective.

As a result of a European Union-funded project, Karlsson, Olsson and Riedel (2016) present in their report several aspects of risk management. First, they discuss existing capability assessment approaches in the European Union (EU) and Baltic Sea Region. Second, empirical data in this field is presented and analyzed. Third, the EU document “Risk Management Capability Assessment Guidelines” (2015/C261/03)” and its potential use are discussed. Fourth, a methodology for risk and capability assessment is proposed as a result of the previous chapters. This report has a clear geographical focus and features conceptual as well as empirical elements.

The broad range of scientific approaches and perspectives in the area of risk management in seaports underlines the necessity for structuring the field. Such a structured overview would allow researchers to integrate their own activities much quicker and to discover relevant research streams for future opportunities. So far, the literature is lacking a quantitative study analyzing bibliometric information of available research work with the aim of framing the main research areas and identifying existing research gaps. For instance, a study conducted by Colicchia and Strozzi (2012) combined a SLR with a citation network analysis to identify directions for future research in the field of supply chain risk management with no focus on seaports. We address this fact with the work presented in this paper. The next chapter presents the methodology applied in the course of this research.

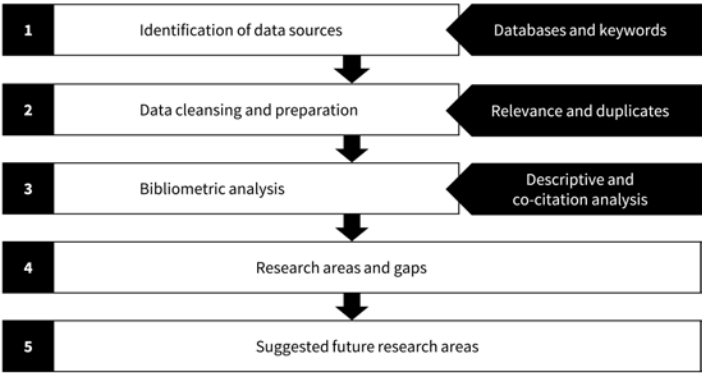

Figure 1: Research Design of the Performed Bibliometric Analysis

3 Methodology

The research design is developed according to specific research questions that address the objectives of this paper. The authors identified three research questions as follows:

1. What are the main and minor research areas of risk management in seaports?
2. What are the current research gaps in the existing literature on risk management in seaports?
3. What are future research areas in the field of risk management in seaports based on the current literature?

In order to answer these research questions, this paper employs a quantitative approach in terms of a bibliometric analysis with a co-citation analysis as the central methodological element. The overall research design of the performed analysis is adapted and further developed from Soni and Kodali (2011, p. 241) incorporating the bibliometric analysis as shown in Figure 1. The period of extracting, cleansing and analyzing the articles lasted from April to June 2017 and involved regular discussions and preparations among the authors.

First, a systematic identification of data sources is carried out by selecting scientific databases and adequate keyword combinations to extract relevant articles creating the data set for further analysis. Second, data cleansing and preparation follows to check for duplicates and irrelevant articles. Additionally, the data set obtained in this phase is transformed into a processible format. Third, the data is analyzed in terms of a descriptive as well as a co-citation analysis. Then the results of the co-citation analysis is further examined in order to reveal the main research areas and gaps of current literature on risk management in seaports. Fourth, future research areas for risk management in seaports are suggested. The steps performed in each phase mentioned above are further detailed in the following.

Two scientific databases were chosen in order to prepare the set of articles for the bibliometric analysis using co-citation analysis. Web of Science (WOS) and Scopus were selected since they provide the largest set of peer-reviewed papers including required citation information as well as valuable cited-in references. Google Scholar was used for extracting the cited-in references for each article. All information combined constitutes the essential input for the co-citation analysis.

Based on the objective of this paper, a specific set of keywords was defined enabling the extraction of suitable articles for the co-citation analysis. The keywords selected cover risk management, risk analysis, risk assessment, and seaport. The keywords were selected according to a related notion analysis that presents the top keywords used for risk management in seaports. These keyword combinations were entered in the search field of Scopus and WOS using the logical operators ”AND” and ”OR” as follow:

1. Risk Management AND (Seaport OR Sea Port),
2. Risk Analysis AND (Seaport OR Sea Port),
3. Risk Assessment AND (Seaport OR Sea Port).

The steps of data cleansing and preparation reflect the filtering mechanism that is required in order to obtain a set of articles that is relevant to the field under investigation. Duplications and articles with missing information were removed from the dataset. Afterward, the abstract for each article was carefully read and

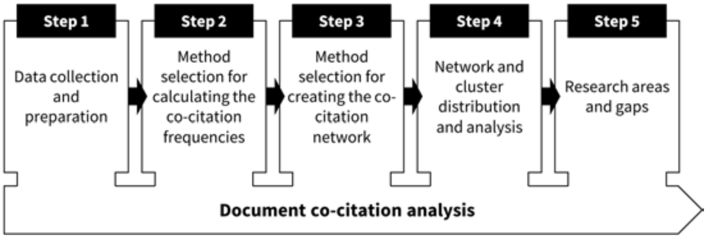

Figure 2: Steps of the Document Co-citation Analysis (based on Gmür, 2003)

examined to remove any irrelevant article. This final dataset of articles is used for the descriptive and co-citation analysis.

The co-citation analysis as a research methodology is based on a co-occurrence quantitative analysis technique that is used to measure the frequency of co-occurrence for a pair of authors, titles, or other keywords in a document to map the dynamics and structure of scientific research (Braam, Moed and van Raan, 1991, p. 24; Gmür, 2003, p. 27). The co-citation starts with defining the selected object and the choice of the approach that is limited to an author or document co-citation analysis. The document co-citation approach reflects the proximity in terms of content within a school of research by analyzing the co-citation between peer-reviewed selected documents. In contrast to this, author co-citation analysis is based on the assumption that any co-citation between documents by any two authors is a suitable measure for the proximity in terms of content in a certain school of research. As the document co-citation analysis promises better results in view of exploring the current research areas of risk management in seaports, this approach is selected for our analysis. The steps of the document co-citation analysis follow the steps shown in Figure 2.

After the data collection and preparation phase, specific methods are selected for calculating the co-citation frequencies as well as to generate the co-citation networks and clusters. Cluster distribution and analysis is followed by analyzing the research stream of each cluster individually via an associated co-citation network that shows the relationship between each reference in the given cluster. Organizational risk analyzer (ORA) is used as the main software to extract and analyze the clusters. ORA is a dynamic meta-network analysis and assessment tool developed by CASOS at Carnegie Mellon in Pittsburgh, U.S. The results of this paper based on the aforementioned methodology are presented in the following chapter.

4 Results

The results of this paper based on the elaborated methodology are presented in this chapter. They comprise the descriptive analysis of the selected articles as well as the process of clustering using the co-citation analysis.

4.1 Descriptive Analysis

Out of the 395 articles obtained from the database inquiries, 108 relevant papers were carefully selected in the phase of data cleansing and preparation. Descriptive figures are used in this subchapter to characterize this final dataset of relevant articles. This descriptive analysis consists of the chronological trend of articles since 1984, top 15 keywords of risk management at seaports as well as the top 10 cited authors.

There is an increasing trend of articles published containing aspects related to risk management, risk assessment, and risk analysis in seaports, particularly starting in 2008 with some deviations occurring in between. As observed in Figure 3, a lower number of articles is observed in 2017 since the analysis was carried out until April 2017.

An extraction of all author keywords from the selected databases was conducted in order to extract the top 15 frequent keywords related to risk management in seaports. Risk assessment and ballast water are frequent keywords that appear in the selected articles. Many articles used 'port' as a keyword associated with the maritime environment whereas a set of other articles used 'seaport' as a core identifier. Ballast water management as well as studies that discuss the various implications of climate change on ports and coastal cities are accompanied by the keywords 'ballast water' and 'climate change'. Several studies are related to the concentration of heavy metals in sediments. All other keywords are presented in Figure 4.

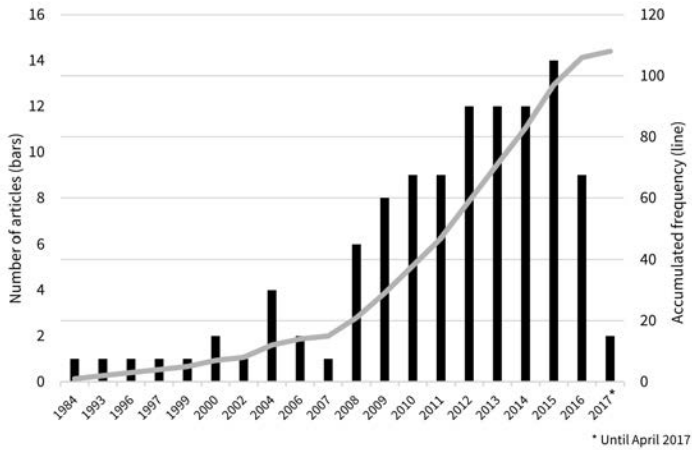

Figure 3: Number of Articles Identified per Year

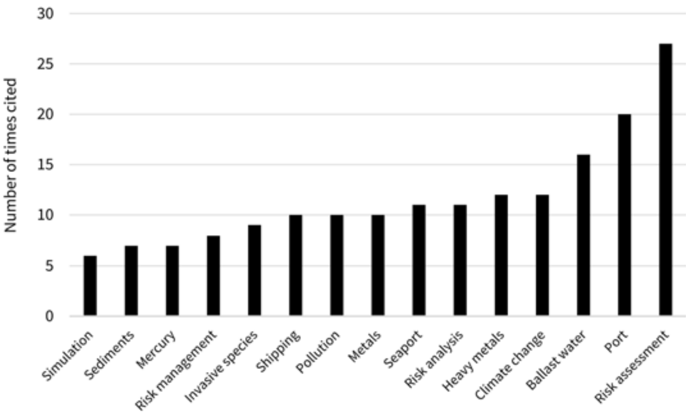

Figure 4: Top 15 Keywords associated with Risk Management in Seaports

The most cited first author based on the citation information from WOS and Scopus in the selected 108 articles focused on papers related to the impact of climate change and natural risks on seaports, such as flood losses in port cities is S. Hallegatte. Similarly, the authors R. L. Wilby, S. Hanson, C. B. Awuor, and H. Sterr, H presented studies related to climate change and flood risk as well as sea-level rise and its impacts on port cities. For instance, S. Hanson provided a related study on the assessment of exposure of large port cities to climate extremes such as flooding and storm surge.

In contrast to the aforementioned authors, P. Trucco focused on the integration of Human and Organizational Factors (HOF) into risk analysis by employing Fault Tree Analysis and a Bayesian Belief Network (BBN). BBNs are used in order to represent dependencies among a set of variables probabilistically (Cooper, 1990, p. 393). Decision support framework for risk management and analysis of accidents in seaports are topics that are as well highly cited (R. M. Darbra, K. Mokhtari). The other set of authors focused on assessment studies related to risk assessment of pollutant concentrations and collision avoidance (D. Haynes, J. M. Mou). The top 10 cited authors are revealed in Figure 5.

Following the descriptive analysis of the selected articles, the results of the cluster analysis based on the document co-citation are presented in the next section.

4.2 Co-citation Analysis

The results of the co-citation analysis are presented in this section based on the aforementioned described steps (see Figure 2).

An additional filtering mechanism was applied to the original list of 108 articles sorting out articles with less than two cited-in references. This means that articles that are not cited or cited only once in other articles in the literature are filtered out. Consequently, 15 articles are excluded from the final dataset. Additionally, all cited-in references for each article were stored separately in Excel worksheets that correspond to each article. These articles were downloaded using the library of Google Scholar and saved as CSV files. In total, 2,702 cited-in references are distributed among the 93 articles.

A 93 x 93 raw co-citation matrix was programmed using Visual Basic for Applications (VBA) in order to calculate the co-citation frequencies. The co-citation matrix is an essential input for the ORA software. A Microsoft Excel macro was

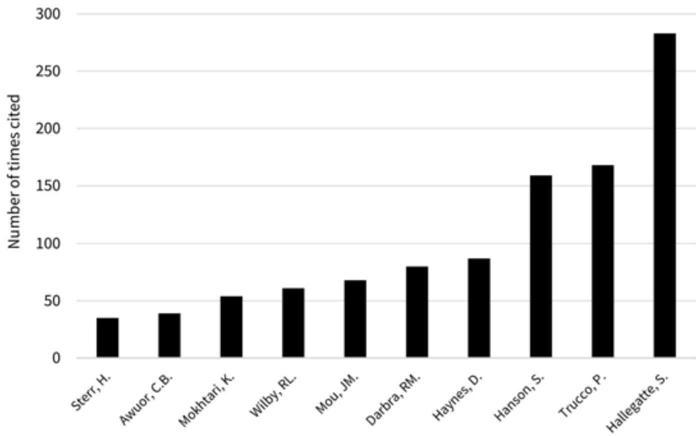

Figure 5: Top 10 Cited Authors in the Field of Risk Management in Seaports

programmed to generate the raw co-citation matrix by comparing the list of cited-in references for each article in each worksheet. The macro loops through each article and records the co-citation frequency in the relevant field in the co-citation matrix.

The CoCit score was chosen as the main method for generating the co-citation network and clusters. According to Gmür (2003, p. 40), the CoCit minimizes the citation relation of both co-citation partners. The method takes a value between 0 and 1. It relates the sum of the co-citation count in relation to the mean and minimum counts of the two individual citations. The CoCit is calculated using the following formula (Gmür, 2003, p. 41):

$$CoCit_{AB} = \frac{(co\text{-}citation)^2}{min(citation_A; citation_B) * mean(citation_A; citation_B)}$$

The analysis is done in the software ORA with a threshold value of 0.01. This threshold value is manually adjusted until a clear pattern is detected. The co-citation network as shown in Figure 6 has emerged with the associated identified eight clusters. Additional revision of the abstracts and introduction parts of the articles is conducted to extract the clusters from the network. Out of the total 67 co-cited articles in the final dataset, 36 are clustered references in the co-citation network. Therefore, the network has a penetration value of 53.7%, which is used to assess the coverage of the co-citation network. This is a higher value compared to the value achieved by (Gmür, 2003, p. 45) who achieved a penetration value of 48% using the CoCit score.

In the following sections, the clusters obtained are further described. The articles referenced as well as their associated reference number can be found in the appendix.

Cluster I: Risk Management of Ballast Water (3 articles)

The first cluster is associated with studies related to risk management of ballast water with a focus on the Baltic Sea. Ballast water management is a complex issue that requires careful assessment of various species that are transported in ballast water (Endresen, et al., 2004, p. 615). The cluster includes a risk assessment study for exemptions related to intra-Baltic shipping using different methods

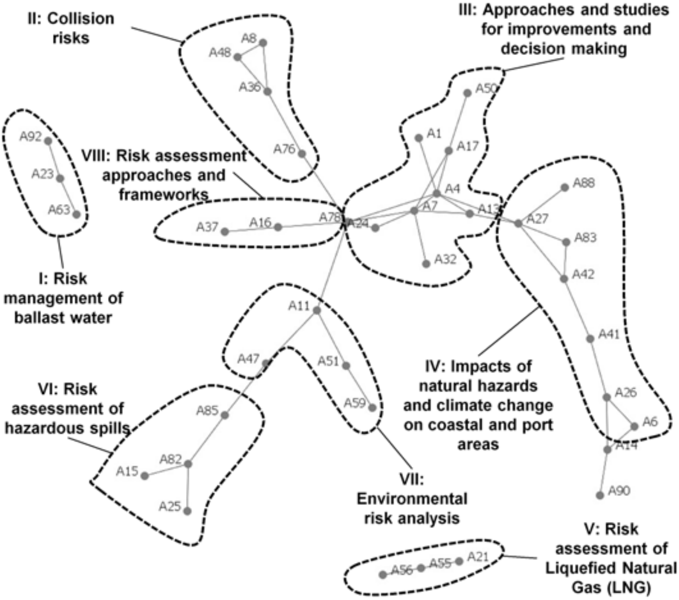

Figure 6: Clusters of the CoCit Co-citation Network

such as environmental matching (David et al. 2013 - A23). The risk assessment study of Gollasch and Leoppaskoski (2007 - A63) covers nine ports distributed in five countries around the Baltic Sea. It presents scenarios of ballast water management for intra-Baltic shipping as well as voyages outside the Baltic. A discharge assessment model for ballast water was developed by David, et al. (2012 - A92) to predict the possibility of ballast water discharge of vessels arriving at ports. This model is based on vessel dimensions and vessel cargo operations.

Cluster II: Collision Risks (4 articles)

This cluster comprises studies that analyze and evaluate collision risks. A marine complexity model was introduced by Wen, et al. (2015 - A2) to analyze the degree of crowding and risk of collision. A similar model was built by Debnath, et al. (2011 - A36) for collision risks using traffic conflicts. A binomial logistic model was derived from traffic conflicts and calibrated by the authors for the Singapore port fairways. As a proactive approach, a study for collision avoidance in busy waterways was conducted by Mou, et al. (2010 - A48). Concerning navigational collisions, Debnath and Chin (2009 - A76) used hierarchical modeling to analyze the relationships between perceived risks, pilot attributes as well as geometric and traffic characteristics of fairways.

Cluster III: Approaches and Studies for Improvements and Decision-making (8 articles)

The third cluster comprises articles that analyze improvement solutions to support decision maker in aspects related to port disruptions, economic losses, mitigation strategies, ship safety index, decision support frameworks, and recommendations for maritime safety. Economic losses of port disruptions, such as extreme wind events, are mentioned in Zhang and Lam (2016 - A1) as well as Zhang and Lam (2015 - A4). Li, et al. (2014 - A17) developed a ship safety index that can aid different parties, such as port authorities, in examining areas that should be inspected, repaired, and maintained based on a relative risk score. A short-term wind forecast is described by Burlando, et al. (2014 - A13) to improve the safety of the largest ports in Northern Tyrrhenian Sea. Lam and Su (2015 - A7) elaborated mitigation strategies based on proactive and reactive measures to minimize the probability of occurrence and severity of various types of port disruptions. A similar approach but related to inventory management for port-of-entry disruption risks including container seaports is discussed by Lewis, et al. (2013 - A24). The authors investigated potential economic and operational impacts with the focus on supply chain inventory as a mitigation strategy. Mokhtari, et al. (2012 - A32) developed a decision support framework using fuzzy set theory (FST) to analyze risk factors for ports and terminal operations and management (PTOM). FST is based on a mathematical framework that simplifies the study of vague conceptual phenomena (Zimmermann, 2011, p. 318). Knapp and Franses (2009 - A50) discussed the improvement in the risk profiling by combining data sources on inspections to improve the maritime safety system that comprises different players such as shipyards.

Cluster IV: Impacts of Natural Hazards and Climate Change on Coastal and Port Areas (7 articles)

Studies of the impact of natural hazards and climate change on coastal and port areas are the focus of this cluster. An economic model for the analysis of disaster prevention investments is developed by Xiao, et al. (2015 - A6). An evaluation framework for climate change and sea level rise potential impacts is presented by Messner et al. (2013 - A26). Hallegatte, et al. (2011 - A41) conducted a similar study by assessing the risks of sea level rise, climate change impacts and storm surge in port cities. Kron (2013 - A27) elaborated in his paper the threats and associated risks of natural hazards and recommended solutions and safeguards to provide an efficient protection. A ranking based on the estimation of the exposure of large port cities to storm surge and coastal flooding is presented by Hanson et al. (2011 - A42). Hallegatte, et al. (2011 - A83) and Raposeior, et al. (2013 - A88) elucidated in their papers the impacts of flood losses along with an assessment of the flooding risk of port and coastal areas.

Cluster V: Risk Assessment of Liquefied Natural Gas (3 articles)

This cluster comprises articles that focus on the risk assessment of Liquefied Natural Gas (LNG) carriers. Risk assessment of LNG carriers using fuzzy TOPSIS method for order preference was conducted by Elsayed, et al. (2014 - A21). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), according to Wang and Elhag (2006, p. 310), is one of the popular approaches for Multiple

Criterion Decision Making (MCDM). A software tool and a methodology for carriers during loading/offloading were developed by Elsayed, et al. (2009 - A55) based on utility theory and multi-attribute risk assessment. A similar approach for multiple attribute risk assessment based on fuzzy inference system (FIS) was developed by Elsayed (2009 - A56). FIS is expressed in terms of “IF-THEN” rules to predict uncertain systems (Kazeminezhad, Etemad-Shahidi and Mousavi, 2005, p. 1710).

Cluster VI: Risk Assessment of Hazardous Spills (4 articles)

This cluster comprises articles that is related to the risk assessment of hazardous spills. These spills include hazardous and noxious substances (HNS) as well as oil spills. Harold, et al. (2014 - A15) developed a methodology to prioritize HNS with a risk prioritization matrix to assess the acute risks of HNS spills. The classification of risk zones represented in risk maps for oil spills was carried out by Singkran (2013 - A26). This classification considered the number of ports and the frequency of oil spill incidents as well. Similarly, an oil spill hazard assessment was conducted by Garcia, et al. (2013 - A82) in Italian ports based on the development of an Oil Spill Hazard Index (OSHI) for hydrocarbons handled at ports and in transit. An assessment of hazards from oil ship discharges, based on oil hazard maps, was the focus of the study conducted by Liubartseva, et al. (2015 - A85).

Cluster VII: Environmental Risk Analysis (4 articles)

This cluster consists of four articles that elaborate the environmental analysis of harbors. A subjective and objective assessment of environmental risks of a tourist harbor in southern Italy was conducted by Irene, et al. (2010 - A51). A multistep indicator-based approach that comprises the development of a tool, suitable environmental quality indicators, and a user-friendly development scheme was carried out by Marin, et al. (2008 - A59) to monitor environmental quality and the associated risks of harbors. Environmental risk analysis of oil handling facilities is presented by Valdor, et al. (2015 - A11). The main pollutant sources and a numerical analysis of several pollution incidents are elaborated by Mestres, et al. (2010 - A47) in order to assess the potential environmental risks.

Cluster VIII: Risk Assessment Approaches and Frameworks (3 articles)

This cluster comprises three articles related to assessment approaches and frameworks for risks in seaports. A fuzzy risk assessment approach for seaports was carried out by John, et al. (2014 - A16) to analyze their complex structure of operations. Pak, et al. (2015 - A78) followed a fuzzy analytical hierarchy process to analyze risk factors that affect navigational safety with their associated implications in seaports. A generic bow-tie analysis framework combining Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) was used by Mokhtari, et al. (2011 - A37) for the risk assessment phase in seaports and offshore terminals. Based on the results of the co-citation analysis, the main research areas and gaps are elaborated on in the next section.

4.3 Main Research Areas and Gaps

The main research areas and gaps in the current literature on risk management in seaports are elaborated in this subchapter based on the results of the co-citation analysis.

4.3.1 Main Research Areas

Two main research areas are revealed based on the third and fourth cluster which consist according to the clusters in the CoCit co-citation network of eight and seven articles respectively. Approaches and studies for analysis and decision-making are the first main research area which encompasses solutions and detailed analysis for improvements as an aid for decision makers. The main aspects considered in this cluster comprise economic, safety and operational aspects. Examples include studies related to economic losses, improvement in maritime safety and operational impacts of inventory management due to port disruptions.

The second main research area is represented by the fourth cluster that presents the impacts of climate change and natural hazards on coastal and port areas. Based on Becker, et al. (2012), anticipations and assessment with regards to the impacts of climate change should be taken into considerations to proactively prepare for different natural hazards such as flooding and sea-level rise.

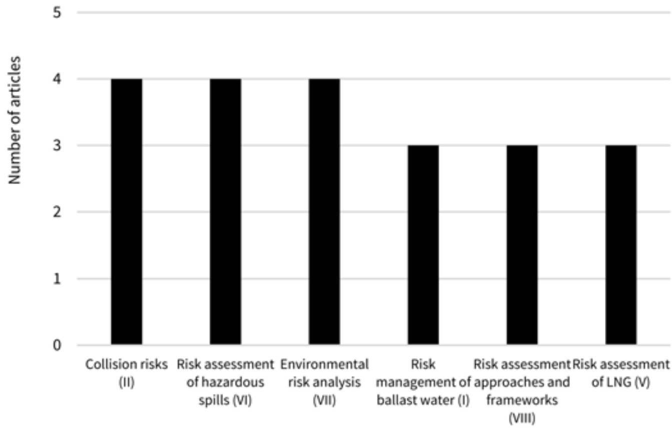

Figure 7: Minor Research Areas

4.3.2 Research Gaps

In order to detect the research gaps, the minor research areas were extracted from the clusters in the co-citation network. The threshold to distinguish major from minor research areas was set to be four articles. Figure 7 shows the minor research areas based on the results of the co-citation analysis.

There is a lack of studies with respect to risk assessment and management methods that can be used by the diverse actors in a seaport. No studies, from the dataset, covered risks such as the improper handling of dangerous goods and the explosions of gases and chemicals. Two research areas focused on the quantitative assessment of risks at seaports in general and specifically on the risk assessment of hazardous spills and LNG. This also includes the integration of cooperative risk management. According to Mokhtari, et al. (2012, p. 5088), appropriate techniques to support the risk management cycle in seaports is required in order to assess the overall risk level. These techniques should reflect the role of each stakeholder at the seaport with regards to the risk management process.

4.4 Suggested Future Research Areas

There is a need to conduct further research on quantitative and qualitative risk assessment and management methods that could be applied to the different operations and sources of risks in seaports. For instance, operations related to the loading, storage, and distribution of cargo. Additional research is suggested with regards to risk assessment methods for the handling of dangerous goods and the explosions of gases and chemicals along with case studies. Furthermore, simulation approaches such as Monte Carlo simulation can support in aggregating the various risks in the port system. Additionally, the future research work should consider cooperative risk management for the parties involved in the different operations of a seaport. A model for cooperative risk management will enable a better preparedness and visibility for risks that occur within the port system. A common language and understanding of risks should be developed and integrated into a database management system in order to increase the risk management know-how on one hand and to increase the visibility among the different members of a port system on the other hand. This will allow the different members to share an understanding of risks facing the seaport and guide them to implement effective proactive measures as well as contingency plans.

5 Conclusion

This research paper analyzes current literature on risk management in seaports and proposes a suitable structure. The methodological approach chosen in this regard is a bibliometric analysis focusing on documents co-citations. From this analysis, two main research areas were extracted: (1) Approaches and studies for improvements and decision-making and (2) Impacts of natural hazards and climate change on coastal and port areas. Besides already existing research streams, also potential research gaps were considered in our analysis. The first deficiency identified is a lack of studies about risk assessment and risk management methods that are suitable for the usage across the different stakeholders in a seaport. Additionally, a gap was detected concerning other types of risks, such as the improper handling of dangerous goods. Therefore, the future research areas should be tailored to quantitative and qualitative risk assessment and risk management methods that could be used by the various stakeholders in the different operations and sources of risk at seaports. This includes the consideration of a cooperative risk management to understand and better identify, assess, and manage the risks among the different stakeholders.

The study presented is limited to specific keywords in the data extraction phase and may hence not cover all scientific papers in the field of risk management in seaports. In addition, the dataset of the databases consulted may not be fully comprehensive. The cluster analysis performed relies on the CoCit score as main method for generating the co-citation network. The clusters created are based on a specific threshold that is manually adjusted. Future work should consider performing a co-citation proximity analysis to achieve a high penetration value. The articles not clustered in in the co-citation analysis presented here could be analyzed further in order to identify additional research trends and research areas. Future research could also consider combining a SLR with a co-citation analysis in order to provide an exhaustive overview of all possible research areas.

Financial Disclosure

This work is supported by the EU project HAZARD (Mitigating the Effects of Emergencies in the Baltic Sea Region Ports). HAZARD is a Flagship Project in the EU Strategy for the Baltic Sea Region, which is partly funded by the EU's Interreg Program.

Appendix Referenzes for the clusters

#	Reference	#	Reference
A1 (III)	Zhang, Y. and Lam, J.S.L., 2016. Estimating economic losses of industry clusters due to port disruptions. Transportation Research Part A: Policy and Practice, 91, pp.17-33.	A11 (VII)	Valdor, P.F., Gómez, A.G. and Puente, A., 2015. Environmental risk analysis of oil handling facilities in port areas. Application to Tarragona harbor (NE Spain). Marine pollution bulletin, 90(1), pp.78-87.
A2	John, A., Yang, Z., Riahi, R. and Wang, J., 2016. A risk assessment approach to improve the resilience of a seaport system using Bayesian networks. Ocean Engineering, 111, pp.136-147.	A12	Przywarty, M., Gucma, L., Marcjan, K. and Bąk, A., 2015. Risk analysis of collision between passenger ferry and chemical tanker in the western zone of the Baltic Sea. Polish Maritime Research, 22(2), pp.3-8.
A3	Vidmar, P. and Perkovič, M., 2015. Methodological approach for safety assessment of cruise ship in port. Safety science, 80, pp.189-200.	A13 (III)	Burlando, M., Pizzo, M., Repetto, M.P., Solari, G., De Gaetano, P. and Tizzi, M., 2014. Short-term wind forecast for the safety management of complex areas during hazardous wind events. Journal of Wind Engineering and Industrial Aerodynamics, 135, pp.170-181.
A4 (III)	Zhang, Y. and Lam, J.S.L., 2015. Estimating the economic losses of port disruption due to extreme wind events. Ocean & Coastal Management, 116, pp.300-310.	A14	Alyami, H., Lee, P.T.W., Yang, Z., Riahi, R., Bonsall, S. and Wang, J., 2014. An advanced risk analysis approach for container port safety evaluation. Maritime Policy & Management, 41(7), pp.634-650.
A5	Azmi, F., Hewitt, C.L. and Campbell, M.L., 2015. A hub and spoke network model to analyse the secondary dispersal of introduced marine species in Indonesia. ICES Journal of Marine Science: Journal du Conseil, 72(3), pp.1069-1077.	A15 (VI)	Harold, P.D., de Souza, A.S., Louchart, P., Russell, D. and Brunt, H., 2014. Development of a risk-based prioritisation methodology to inform public health emergency planning and preparedness in case of accidental spill at sea of hazardous and noxious substances (HNS). Environment international, 72, pp.157-163.
A6 (IV)	Xiao, Y.B., Fu, X., Ng, A.K. and Zhang, A., 2015. Port investments on coastal and marine disasters prevention: Economic modeling and implications. Transportation Research Part B: Methodological, 78, pp.202-221.	A16 (VIII)	John, A., Paraskevadakis, D., Bury, A., Yang, Z., Riahi, R. and Wang, J., 2014. An integrated fuzzy risk assessment for seaport operations. Safety Science, 68, pp.180-194.
A7 (III)	Lam, J.S.L. and Su, S., 2015. Disruption risks and mitigation strategies: an analysis of Asian ports. Maritime Policy & Management, 42(5), pp.415-435.	A17 (III)	Li, K.X., Yin, J. and Fan, L., 2014. Ship safety index. Transportation research part A: policy and practice, 66, pp.75-87.
A8 (II)	Wen, Y., Huang, Y., Zhou, C., Yang, J., Xiao, C. and Wu, X., 2015. Modelling of marine traffic flow complexity. Ocean Engineering, 104, pp.500-510.	A18	Filina-Dawidowicz, L., 2014. Rationalization of servicing reefer containers in sea port area with taking into account risk influence. Polish Maritime Research, 21(2), pp.76-85.
A9	Paulauskienė, T. and Jucikė, I., 2015. Aquatic oil spill cleanup using natural sorbents. Environmental Science and Pollution Research, 22(19), pp.14874-14881.	A19	Sany, S.B.T., Hashim, R., Salleh, A., Safari, O., Mehdinia, A. and Rezayi, M., 2014. Risk assessment of polycyclic aromatic hydrocarbons in the West Port semi-enclosed basin (Malaysia). Environmental Earth Sciences, 71(10), pp.4319-4332.
A10	Erol, S. and Başar, E., 2015. The analysis of ship accident occurred in Turkish search and rescue area by using decision tree. Maritime Policy & Management, 42(4), pp.377-388.	A20	Suzdalev, S., Gulbinskas, S., Sivkov, V. and Bukanova, T., 2014. Solutions for effective oil spill management in the south-eastern part of the Baltic Sea. Baltica, 27(1), pp.3-8.

#	Reference	#	Reference
A21 (V)	Elsayed, T., Marghany, K. and Abdulkader, S., 2014. Risk assessment of liquefied natural gas carriers using fuzzy TOPSIS. Ships and Offshore Structures, 9(4), pp.355-364.	A31	Chulkov, D.V., 2012. Managing new technology investment for underwater security of ports. Journal of Transportation Security, 5(2), pp.95-105.
A22	Bruzzone, A., Longo, F. and Tremori, A., 2013. An interoperable simulation framework for protecting port as critical infrastructures. International Journal of System of Systems Engineering, 4(3-4), pp.243-260.	A32 (III)	Mokhtari, K., Ren, J., Roberts, C. and Wang, J., 2012. Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach. Expert Systems with Applications, 39(5), pp.5087-5103.
A23 (I)	David, M., Gollasch, S. and Leppäkoski, E., 2013. Risk assessment for exemptions from ballast water management–The Baltic Sea case study. Marine pollution bulletin, 75(1), pp.205-217.	A33	Vilko, J. and Hallikas, J., 2012. Origin and impact of supply chain risks affecting supply security. International Journal of Shipping and Transport Logistics, 4(2), pp.110-123.
A24 (III)	Lewis, B.M., Erera, A.L., Nowak, M.A. and Chelsea C III, W., 2013. Managing inventory in global supply chains facing port-of-entry disruption risks. Transportation Science, 47(2), pp.162-180.	A34	Hancilar, U., 2012. Identification of elements at risk for a credible tsunami event for Istanbul. Natural Hazards and Earth System Sciences, 12(1), p.107.
A25 (VI)	Singkran, N., 2013. Classifying risk zones by the impacts of oil spills in the coastal waters of Thailand. Marine pollution bulletin, 70(1), pp.34-43.	A35	Kebede, A.S., Nicholls, R.J., Hanson, S. and Mokrech, M., 2010. Impacts of climate change and sea-level rise: a preliminary case study of Mombasa, Kenya. Journal of Coastal Research, 28(1A), pp.8-19.
A26 (IV)	Messner, S., Moran, L., Reub, G. and Campbell, J., 2013. Climate change and sea level rise impacts at ports and a consistent methodology to evaluate vulnerability and risk. WIT Transactions on Ecology and the Environment, 169, pp.141-153.	A36 (II)	Debnath, A.K., Chin, H.C. and Haque, M.M., 2011. Modelling port water collision risk using traffic conflicts. The Journal of Navigation, 64(4), p.645.
A27 (IV)	Kron, W., 2013. Coasts: the high-risk areas of the world. Natural hazards, 66(3), pp.1363-1382.	A37 (VIII)	Mokhtari, K., Ren, J., Roberts, C. and Wang, J., 2011. Application of a generic bow-tie based risk analysis framework on risk management of sea ports and offshore terminals. Journal of Hazardous Materials, 192(2), pp.465-475.
A28	Babu, D.S., Sivalingam, S. and Machado, T., 2012. Need for adaptation strategy against global sea level rise: an example from Saudi coast of Arabian gulf. Mitigation and Adaptation Strategies for Global Change, 17(7), pp.821-836.	A38	Lattila, L. and Saranen, J., 2011. Multimodal transportation risk in Gulf of Finland Region. World Review of Intermodal Transportation Research, 3(4), pp.376-394.
A29	Perrodin, Y., Donguy, G., Bazin, C., Volatier, L., Durrieu, C., Bony, S., Devaux, A., Abdelghafour, M. and Moretto, R., 2012. Ecotoxicological risk assessment linked to infilling quarries with treated dredged seaport sediments. Science of the Total Environment, 431, pp.375-384.	A39	Hassler, B., 2011. Accidental versus operational oil spills from shipping in the Baltic Sea: risk governance and management strategies. Ambio, 40(2), pp.170-178.
A30	Cruz, C.O. and Marques, R.C., 2012. Risk-sharing in seaport terminal concessions. Transport Reviews, 32(4), pp.455-471.	A40	Choi, Y., 2011. The efficiency of major ports under logistics risk in Northeast Asia. Asia-Pacific Journal of Operational Research, 28(01), pp.111-123.

#	Reference	#	Reference
A41 (IV)	Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C. and Wood, R.M., 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. Climatic change, 104(1), pp.113-137.	A50 (III)	Knapp, S. and Franses, P.H., 2010. Comprehensive review of the maritime safety regimes: Present status and recommendations for improvements. Transport reviews, 30(2), pp.241-270.
A42 (IV)	Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Morlot, J., Herweijer, C. and Chateau, J., 2011. A global ranking of port cities with high exposure to climate extremes. Climatic change, 104(1), pp.89-111.	A51 (VII)	Irene, P., Paolo, V., Donatella, V., Alberto, M.J., Mauro, F. and Giovanni, Z., 2010. Mapping the environmental risk of a tourist harbor in order to foster environmental security: objective vs. subjective assessments. Marine pollution bulletin, 60(7), pp.1051-1058.
A43	Farzingohar, M., Ibrahim, Z.Z. and Yasemi, M., 2011. Oil spill modeling of diesel and gasoline with GNOME around Rajaee Port of Bandar Abbas, Iran. Iranian Journal of Fisheries Sciences, 10(1), pp.35-46.	A52	Choueri, R.B., Cesar, A., Abessa, D.M.D.S., Torres, R.J., Riba, I., Pereira, C.D.S., Nascimento, M.R.L., Morais, R.D., Mozeto, A.A. and DelValls, T.A., 2010. Harmonised framework for ecological risk assessment of sediments from ports and estuarine zones of North and South Atlantic. Ecotoxicology, 19(4), pp.678-696.
A44	Fabiano, B., Curro, F., Reverberi, A.P. and Pastorino, R., 2010. Port safety and the container revolution: A statistical study on human factor and occupational accidents over the long period. Safety Science, 48(8), pp.980-990.	A53	Stancheva, M., 2009. Indicative GIS-based segmentation of the Bulgarian Black Sea coastline for risk assessment. Compt Rend Acad Bulg Sci, 62(10), pp.1311-1318.
A45	Akhtar, J., Bjørnskau, T. and Veisten, K., 2010. Assessing security measures reducing terrorist risk: inverse ex post cost-benefit and cost-effectiveness analyses of Norwegian airports and seaports. Journal of Transportation Security, 3(3), pp.179-195.	A54	Svedberg, U., Petrini, C. and Johanson, G., 2009. Oxygen depletion and formation of toxic gases following sea transportation of logs and wood chips. Annals of Occupational Hygiene, 53(8), pp.779-787.
A46	Froehner, S., Maceno, M., Da Luz, E.C., Souza, D.B. and Machado, K.S., 2010. Distribution of polycyclic aromatic hydrocarbons in marine sediments and their potential toxic effects. Environmental monitoring and assessment, 168(1), pp.205-213.	A55 (V)	Elsayed, T., Leheta, H. and Shehadeh, M., 2009. Multi-attribute risk assessment of LNG carriers during loading/offloading at terminals. Ships and Offshore Structures, 4(2), pp.127-131.
A47 (VII)	Mestres, M., Sierra, J.P., Mösso, C. and Sánchez-Arcilla, A., 2010. Sources of contamination and modelled pollutant trajectories in a Mediterranean harbour (Tarragona, Spain). Marine pollution bulletin, 60(6), pp.898-907.	A56 (V)	Elsayed, T., 2009. Fuzzy inference system for the risk assessment of liquefied natural gas carriers during loading/offloading at terminals. Applied Ocean Research, 31(3), pp.179-185.
A48 (II)	Mou, J.M., Van der Tak, C. and Ligteringen, H., 2010. Study on collision avoidance in busy waterways by using AIS data. Ocean Engineering, 37(5), pp.483-490.	A57	Snoussi, M., Ouchani, T., Khouakhi, A. and Niang-Diop, I., 2009. Impacts of sea-level rise on the Moroccan coastal zone: Quantifying coastal erosion and flooding in the Tangier Bay. Geomorphology, 107(1), pp.32-40.
A49 (VII)	Shang, K.C. and Tseng, W.J., 2010. A risk analysis of stevedoring operations in seaport container terminals. Journal of Marine Science and Technology, 18(2), pp.201-210.	A58	Na, U.J. and Shinozuka, M., 2009. Simulation-based seismic loss estimation of seaport transportation system. Reliability Engineering & System Safety, 94(3), pp.722-731.

#	Reference	#	Reference
A59 (VII)	Marin, V., Moreno, M., Vassallo, P., Vezzulli, L. and Fabiano, M., 2008. Development of a multistep indicator-based approach (MIBA) for the assessment of environmental quality of harbours. ICES Journal of Marine Science: Journal du Conseil, 65(8), pp.1436-1441.	A69	Wood, N.J., Good, J.W. and Goodwin, R.F., 2002. Vulnerability assessment of a port and harbor community to earthquake and tsunami hazards: integrating technical expert and stakeholder input. Natural Hazards Review, 3(4), pp.148-157.
A60	Gravelle, G. and Mimura, N., 2008. Vulnerability assessment of sea-level rise in Viti Levu, Fiji Islands. Sustainability Science, 3(2), pp.171-180.	A70	Haynes, D. and Johnson, J.E., 2000. Organochlorine, heavy metal and polyaromatic hydrocarbon pollutant concentrations in the Great Barrier Reef (Australia) environment: a review. Marine Pollution Bulletin, 41(7), pp.267-278.
A61	Trucco, P., Cagno, E., Ruggeri, F. and Grande, O., 2008. A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation. Reliability Engineering & System Safety, 93(6), pp.845-856.	A71	El-Raey, M., Frihy, O., Nasr, S.M. and Dewidar, K.H., 1999. Vulnerability assessment of sea level rise over Port Said Governorate, Egypt. Environmental Monitoring and Assessment, 56(2), pp.113-128.
A62	Awuor, C.B., Orindi, V.A. and Ochieng Adwera, A., 2008. Climate change and coastal cities: the case of Mombasa, Kenya. Environment and Urbanization, 20(1), pp.231-242.	A72	Hoque, M.M., Storm-Surge Flooding in Chittagong City and Associated Risk. In North American Water and Environment Congress & Destructive Water: (pp. 3701-3701). ASCE.
A63 (I)	Gollasch, S. and Leppäkoski, E., 2007. Risk assessment and management scenarios for ballast water mediated species introductions into the Baltic Sea. Aquatic Invasions, 2(4), pp.313-340.	A73	Rao, P.G. and Raghavan, K.V., 1996. Hazard and risk potential of chemical handling at ports. Journal of Loss Prevention in the Process Industries, 9(3), pp.199-204.
A64	Edwards, A.M.C. and Winn, P.S.J., 2006. The Humber Estuary, Eastern England: Strategic planning of flood defences and habitats. Marine Pollution Bulletin, 53(1), pp.165-174.	A74	Rømer, H., Brockhoff, L., Haastrup, P. and Petersen, H.S., 1993. Marine transport of dangerous goods. Risk assessment based on historical accident data. Journal of loss prevention in the process industries, 6(4), pp.219-225.
A65	Ho, M.W. and Ho, K.H.D., 2006. Risk management in large physical infrastructure investments: The context of seaport infrastructure development and investment. Maritime economics & logistics, 8(2), pp.140-168.	A75	Snowball, D.J. and Macgill, S.M., 1984. Coping with risk: the case of gas facilities in Scotland. Environment and Planning C: Government and Policy, 2(3), pp.343-360.
A66	Palazzi, E., Currò, F. and Fabiano, B., 2004. Simplified modelling for risk assessment of hydrocarbon spills in port area. Process Safety and Environmental Protection, 82(6), pp.412-420.	A76 (II)	Debnath, A. and Chin, H., 2009. Hierarchical modeling of perceived collision risks in port fairways. Transportation Research Record: Journal of the Transportation Research Board, (2100), pp.68-75.
A67	Darbra, R.M. and Casal, J., 2004. Historical analysis of accidents in seaports. Safety Science, 42(2), pp.85-98.	A77	Na, U.J., Chaudhuri, S.R. and Shinozuka, M., 2009. Effects of spatial variation of soil properties on seismic performance of port structures. Soil Dynamics and Earthquake Engineering, 29(3), pp.537-545.
A68	Kassomenos, P.A., 2004. Risk analysis for environmental hazards: the case of oil spills, in Crete. Global Nest: the International Journal, 6(1), pp.39-51.	A78 (VIII)	Pak, J.Y., Yeo, G.T., Oh, S.W. and Yang, Z., 2015. Port safety evaluation from a captain's perspective: The Korean experience. Safety science, 72, pp.172-181.

#	Reference	#	Reference
A79	Walker, W.E., 2000. POLSSS: overview and cost-effectiveness analysis. Safety science, 35(1), pp.105-121.	A87	Shih, C.H., Huang, P.H., Yamamura, S. and Chen, C.Y., 2012. Design optimal control of ship maneuver patterns for collision avoidance: a review. Journal of Marine Science and Technology, 20(2), pp.111-121.
A80	Rooney, R.M., Bartram, J.K., Cramer, E.H., Mantha, S., Nichols, G., Suraj, R. and Todd, E.C., 2004. A review of outbreaks of waterborne disease associated with ships: evidence for risk management. Public health reports, 119(4), pp.435-442.	A88 (IV)	Raposeiro, P.D., Fortes, C.J., Capitão, R., Reis, M.T., Ferreira, J.C., Pereira, M.T.S. and Guerreiro, J., 2013. Preliminary phases of the HIDRALERTA system: Assessment of the flood levels at S. João da Caparica beach, Portugal. Journal of Coastal Research, 65(sp1), pp.808-813. Vancouver
A81	Wilby, R.L. and Keenan, R., 2012. Adapting to flood risk under climate change. Progress in Physical Geography, 36(3), pp.348-378.	A89	Sterr, H., 2008. Assessment of vulnerability and adaptation to sea-level rise for the coastal zone of Germany. Journal of Coastal Research, 24(2), pp.380-393.
A82 (VI)	Garcia, D.A., Bruschi, D., Cumo, F. and Gugliermetti, F., 2013. The Oil Spill Hazard Index (OSHI) elaboration. An oil spill hazard assessment concerning Italian hydrocarbons maritime traffic. Ocean & coastal management, 80, pp.1-11.	A90	Yang, Z., Ng, A.K. and Wang, J., 2013. Prioritising security vulnerabilities in ports. International Journal of Shipping and Transport Logistics, 5(6), pp.622-636.
A83 (IV)	Hallegatte, S., Green, C., Nicholls, R.J. and Corfee-Morlot, J., 2013. Future flood losses in major coastal cities. Nature climate change, 3(9), pp.802-806.	A91	Duarte, H.D.O., Droguett, E.L., Araújo, M. and Teixeira, S.F., 2013. Quantitative ecological risk assessment of industrial accidents: The case of oil ship transportation in the coastal tropical area of northeastern Brazil. Human and Ecological Risk Assessment: An International Journal, 19(6), pp.1457-1476.
A84	Xiong, S., Long, H., Tang, G., Wan, J. and Li, H., 2015. The management in response to marine oil spill from ships in China: A systematic review. Marine pollution bulletin, 96(1), pp.7-17.	A92 (I)	David, M., Perkovič, M., Suban, V. and Gollasch, S., 2012. A generic ballast water discharge assessment model as a decision supporting tool in ballast water management. Decision support systems, 53(1), pp.175-185.
A85 (VI)	Liubartseva, S., De Dominicis, M., Oddo, P., Coppini, G., Pinardi, N. and Greggio, N., 2015. Oil spill hazard from dispersal of oil along shipping lanes in the Southern Adriatic and Northern Ionian Seas. Marine pollution bulletin, 90(1), pp.259-272.	A93	Pourabadehei, M. and Mulligan, C.N., 2016. Effect of the resuspension technique on distribution of the heavy metals in sediment and suspended particulate matter. Chemosphere, 153, pp.58-67.
A86	Grifoll, M., Jordà, G., Espino, M., Romo, J. and García-Sotillo, M., 2011. A management system for accidental water pollution risk in a harbour: The Barcelona case study. Journal of Marine Systems, 88(1), pp.60-73.		

References

Alyami, H., Z. Yang, R. Riahi, S. Bonsall, and J. Wang (2016). "Advanced uncertainty modelling for container port risk analysis". In: *Accident; analysis and prevention*.

Andritsos, F. and M. Mosconi, eds. (2010). *Port Security in EU: a Systemic Approach*.

Becker, A., S. Inoue, M. Fischer, and B. Schwegler (2012). "Climate change impacts on international seaports: Knowledge, perceptions, and planning efforts among port administrators". In: *Climatic change* 110.1, pp. 5–29.

Braam, R. R., H. F. Moed, and A. F. J. van Raan (1991). "Mapping of science by combined co-citation and word analysis I. Structural aspects". In: *Journal of the American Society for information science* 42.4, p. 233.

Bruzzone, A., R. Mosca, R. Revetria, and S. Rapallo (2000). "Risk analysis in harbor environments using simulation". In: *Safety Science* 35.1-3, pp. 75–86.

Christopher, K. (2015). *Port security management*. 2. ed., [elektronische Ressource]. Boca Raton, Fla.: CRC Press/Taylor & Francis.

Colicchia, C. and F. Strozzi (2012). "Supply chain risk management: A new methodology for a systematic literature review". In: *Supply Chain Management: An International Journal* 17.4, pp. 403–418.

Cooper, G. F. (1990). "The computational complexity of probabilistic inference using Bayesian belief networks". In: *Artificial intelligence* 42.2-3, pp. 393–405.

Coyle, J. J., R. A. Novack, B. Gibson, and E. J. Bardi (2010). *Transportation: A supply chain perspective*. Cengage Learning.

Endresen, Ø., H. L. Behrens, S. Brynestad, A. B. Andersen, and R. Skjong (2004). "Challenges in global ballast water management". In: *Marine Pollution Bulletin* 48.7, pp. 615–623.

Eurostat (2017). *Maritime Ports Freight and Passenger Statistics*.

Garvey, P. R. (2008). *Analytical methods for risk management: A systems engineering perspective*. Crc Press.

Gharehgozli, A. H., J. Mileski, A. Adams, and W. von Zharen (2016). "Evaluating a "wicked problem": A conceptual framework on seaport resiliency in the event of weather disruptions". In: *Technological Forecasting and Social Change* 121, pp. 65–75.

Gmür, M. (2003). "Co-citation analysis and the search for invisible colleges: A methodological evaluation". In: *Scientometrics* 57.1, pp. 27–57.

Huber, T. (2014). ""Global Ports" in der maritimen Transportwirtschaft: Akteursbasierende Bewertung des weltweiten Netzwerks von Hafenstandorten". Dissertation. Regensburg.

International Maritime Organization (2003). *International Ship and Port Facility Security Code*.

International Organization for Standardization (2009). *Risk management - Principles and guidelines*.

John, A., D. Paraskevadakis, A. Bury, Z. Yang, R. Riahi, and J. Wang (2014). "An integrated fuzzy risk assessment for seaport operations". In: *Safety Science* 68, pp. 180–194.

Jüttner, U. (2005). "Supply chain risk management: Understanding the business requirements from a practitioner perspective". In: *The International Journal of Logistics Management* 16.1, pp. 120–141.

Karlsson, B., A. J. Olsson, and M. Riedel, eds. (2016). *From Gaps to Caps: Report on National Capability and Risk Assessments and related challenges in the Baltic Sea Region*.

Kazeminezhad, M. H., A. Etemad-Shahidi, and S. J. Mousavi (2005). "Application of fuzzy inference system in the prediction of wave parameters". In: *Ocean Engineering* 32.14, pp. 1709–1725.

La Tovar de Fé, B., L. Trujillo, and S. Jara-Díaz (2004). "Organization and regulation of the port industry: Europe and Spain". In: *Essays on Microeconomics and Industrial Organisation, 2nd edn, Physica-Verlag, a Springer-Verlag Company, Germany*.

Martino, M. de, L. Errichiello, A. Marasco, and A. Morvillo (2013). "Logistics innovation in Seaports: An inter-organizational perspective". In: *Research in Transportation Business & Management* 8, pp. 123–133.

Mokhtari, K., J. Ren, C. Roberts, and J. Wang (2012). "Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach". In: *Expert systems with applications* 39.5, pp. 5087–5103.

Soni, G. and R. Kodali (2011). "A critical analysis of supply chain management content in empirical research". In: *Business Process Management Journal* 17.2, pp. 238–266.

UNCAD (2016). *Review of Maritime Transport 2016*. [S.l.]: United Nations.

UNCTAD (2015). *Review of Maritime Transport 2015*. Review of maritime transport. New York and Geneva: United Nations.

U.S. Department of Homeland Security, ed. (2003). *Protecting America's Ports: Maritime Transportation Security Act of 2002*.

Valdor, P. F., A. G. Gómez, and A. Puente (2015). "Environmental risk analysis of oil handling facilities in port areas. Application to Tarragona harbor (NE Spain)". In: *Marine Pollution Bulletin* 90.1, pp. 78–87.

Wang, Y.-M. and T. M. S. Elhag (2006). "Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment". In: *Expert systems with applications* 31.2, pp. 309–319.

Zhao, B. (2016). "Facts and lessons related to the explosion accident in Tianjin Port, China". In: *Natural Hazards* 84.1, pp. 707–713.

Zimmermann, H.-J. (2011). *Fuzzy set theory—and its applications*. Springer Science & Business Media.

About HICL

Since 2006 the annual conference Hamburg International Conference of Logistics (HICL) at Hamburg University of Technology (TUHH) is dedicated to facilitate the exchange of ideas and contribute to the improved understanding and practice of Logistics and Supply Chain Management. HICL provides a creative environment, which attracts researchers and practitioners from all over the world.

This volume contains research contributions by an international group of authors addressing innovative and technology-based approaches for logistics and supply chains. They present business models and investment options for enhanced strategic decision making as well as recent approaches for supply chain risk management.

This volume, edited by Wolfgang Kersten, Thorsten Blecker and Christian Ringle, provides valuable insights into the digitalization of Supply Chain Management and Logistics with regard to:

- Innovation and Technology Management
- Advanced Manufacturing and Industry 4.0
- Risk and Security Management

ISBN (Print): 9783745043280

ISSN (Print) : 2635-4430
ISSN (Online) : 2365-5070